THE PERFORMANCE AND PHYSIOLOGICAL RESPONSES TO THE EXTRA-TIME PERIOD OF SOCCER

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ABSTRACT

Soccer matches have a typical duration of 90 min. However, when matches are drawn in some knockout cup scenarios and an outright winner is required, an additional 30 min period, termed extra-time (ET), is played. The performance and physiological responses to 90 min of soccer-specific exercise have been extensively investigated, however; there is a paucity of research investigating the demands of 120 min of soccer-specific exercise (i.e., matches requiring ET). Accordingly, the aims of this thesis were 1) to elucidate professional practitioner perceptions of ET, 2) to investigate the performance and physiological responses during prolonged actual and simulated match-play, and 3) to examine the influence of a nutritional intervention on performance during ET.

To actuate aim one, a qualitative approach (i.e., an online survey) was used to assess practitioner perceptions of ET and their current applied practices. To accomplish aim two, quantitative research projects utilising performance analysis techniques and an analogue of match-play (simulated soccer match) were used. To actuate aim three, the same analogue of match-play was used to investigate the effect of carbohydrate-electrolyte gels ingested prior to ET on performance and physiology.

Practitioners generally account for ET when preparing and recovering players and the majority (91%) of practitioners want research to be conducted on ET. Using notational analysis, reductions in technical performance (i.e., passing and dribbling) were observed during ET. Furthermore, when using a simulated match protocol, perturbations in both performance and physiology compared to the previous 90 min of exercise occur. Specifically reductions in both physical (i.e., sprint speeds) and technical (i.e., shooting speed) parameters, taxing of endogenous fuel sources, dehydration, and shifts in substrate utilisation (i.e., a move towards fat oxidation as a fuel source) were observed. The ingestion of carbohydrate-electrolyte gels prior to ET improved dribbling performance, however; this intervention was unable to attenuate decrements in physical performance and hydration status.

In conclusion, ET influences both soccer-specific performance and physiological responses. In agreement with practitioners working in professional soccer, more research is required to investigate the efficacy of interventions (particularly hydro-nutritional interventions) that improve performance and ameliorate perturbations in physiology and metabolism.

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DECLARATION

I declare that the work contained in this thesis has not been submitted for any other award and that it is all my own work. I also confirm that this work fully acknowledges opinions, ideas and contributions from the work of others.

Any ethical clearance for the research presented in this thesis has been approved. Approval has been sought and granted by the Health and Life Sciences Faculty Ethics committee at Northumbria University at Newcastle.

I declare that the Word Count of this Thesis is 43,016 words.

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TABLE OF ABBREVIATIONS

Abbreviation	Definition
Akt	Protein kinase B
ANOVA	Analysis of variance
AU	Arbitrary unit
BM	Body mass
Ca^{2+}	Calcium ion
CHO	Carbohydrate
CI	95% Confidence Interval
CMJ	Countermovement Jump
CK	Creatine Kinase
CV	Coefficient of Variation
ELISA	Enzyme Linked Immunosorbent Assay
E*N*	Epoch (time)
ES	Effect size
ET	Extra-time
FFA	Free fatty acid
FIFA	Federation Internationale de Football Association
GPS	Global Positioning Systems
Hb	Haemoglobin
HCO^{3-}	Bicarbonate ion
Hct	Haematocrit

HSL	Hormone-sensitive lipase
HT	Half-time
HR	Heart rate
IL-6	Interleukin-6
K+	Potassium ion
LIST	Loughborough Intermittent Shuttle Test
LSPT	Loughborough Soccer Passing Test
LSD	Least significant difference
η^2	Partial-eta^2
Na+	Sodium ion
NEFA	Non-esterified fatty acid
PA	Performance analysis
pCO2	Partial pressure of carbon dioxide
P_i	Inorganic phosphate
PLA	Placebo
PT	Performance test
RPE	Rating of perceived exertion
RSA	Repeated sprint ability
RSM	Repeated sprint maintenance
SD	Standard deviation
SMS	Soccer Match Simulation
T_{core}	Core temperature
TE	Typical error
UEFA	Union of European Football Associations

$\dot{V}O_{2max}$	Maximal oxygen uptake

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INTRODUCTION
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1.0 INTRODUCTION

Soccer (also known as association football) is a high-intensity intermittent team sport, typically played over two 45 min halves that are separated by a 15 min break. Due to soccer's worldwide popularity and the large economic incentives associated with successful performance, there is a large canon of literature investigating a diverse range of soccer-related topics. Indeed, a PubMed search for the term "soccer" derives over 7500 published research articles (as of June 2016). Within these research articles, many have quantified the performance and physiological responses to 90 min of match-play, while also investigating the effect of various ergogenic aids on soccer-specific performance. One aspect of soccer research that has received relatively little attention to date is the extra-time (ET) period.

In matches where an outright winner is required, this 30 min period of soccer match-play commences five minutes after the cessation of normal time and is split into two 15 min halves that are each separated by a two minute break. The structured 30 min period has been part of official Fédération Internationale de Football Association (FIFA) rules for a number of years, and indeed was included as early as 1897 in the English Football Association's rules of play (Slade, 2013). In the 1990's and early 2000's, soccer organising bodies trialled different formats of ET; including, the "golden goal" (first team to score in ET wins the match) and "silver goal" (a team who concedes in ET has until the rest of that 15 min period to equalise or the opposition wins) rules. However, current legislation requires that a full 30 min period of play is performed throughout all competitions, where necessary.

Since 1986, 35% of senior FIFA World Cup knockout matches have required ET, including 50% of matches at the 2014 competition, up from 25% at the 2002 and 2010 FIFA World Cup's, and 38% at the 2006 competition. Furthermore, in the annually held English League Cup competition, 23% of matches required ET from August 2011 to February 2015. Moreover, during May 2016, six major cup finals in European soccer required ET (i.e., in the UEFA Champions

League, Taça de Portugal, Spanish Copa del Rey, German DFB-Pokal, English FA Cup, and Coppa Italia). Despite the prevalence of ET in international and domestic cup competitions, a paucity of research related to this additional period of play currently exists. This is surprising, as the rewards for winning a match in ET are both large from an economic stand point (teams receive money for every match won in a cup competition) and also means that a penalty shootout that follows ET is no longer required, which is often considered as a "lottery". Therefore, a better understanding of what occurs both physiologically and performance-wise during ET will provide coaches and players with key information related to this important period of play.

Owing to the small body of literature currently available, this literature review will infer implications for potential areas of ET research that is derived primarily from studies using 90 min models of soccer-specific exercise. Specifically, the review will synthesise information derived from qualitative and quantitative research investigations that have examined performance and physiological changes during both soccer-specific (i.e., actual and simulated match-play) and non-soccer-specific activity (with specific durations of 120 min), the effect of nutritional ergogenic aids on soccer-specific performance, and also the current issues facing professional practitioners in soccer.

1.1 THE USE OF QUALITATIVE RESEARCH TO EXPLORE ISSUES IN SOCCER

Qualitative research is a methodical approach used in a wide range of disciplines, predominately to investigate human behaviour and the factors influencing behavioural processes (Patton, 2015). In the field of soccer, qualitative research has been used to specifically gather in-depth information from practitioners in a professional environment to enhance understanding of their behaviour. This allows for the design of ecologically valid research projects, the enhancement of coach and player knowledge, and also has the potential to influence the policies of governing bodies. Drust & Green (2013) highlight the importance of qualitative, or descriptive, research in a theoretical model similar to that of Bishop (2008) (see Figure 1.1). Within this model, the authors suggest that researchers should investigate the aetiology of a problem

by conducting descriptive/qualitative research, thereby gaining an understanding into the possible barriers preventing uptake, while undergoing studies to test the effectiveness of an intervention and its possible implementation in an applied setting (Figure 1.1). This theoretical framework will be used as the basis for this thesis, due to the limited evidence base currently available on ET and thus the need for robust investigations covering all aspects of the model.

Contemporary qualitative research involving professional soccer practitioners has investigated the use of training load and player monitoring (Akenhead & Nassis, 2015), warm-up and half-time practices (Towlson et al., 2013), and injury prevention strategies (McCall et al., 2014, McCall et al., 2015). For example, Towlson et al., (2013) surveyed 19 practitioners working in the top two levels of English professional soccer about their practices related to warm-up strategies, the situational and theoretical factors that underpin their use, and their value in enhancing player work-rate and ameliorating injury risk. This work has subsequently informed quantitative research projects investigating the influence of warm-up strategies on intermittent exercise performance (i.e., Edholm et al., 2014; Russell et al., 2015a; Zois et al., 2015).

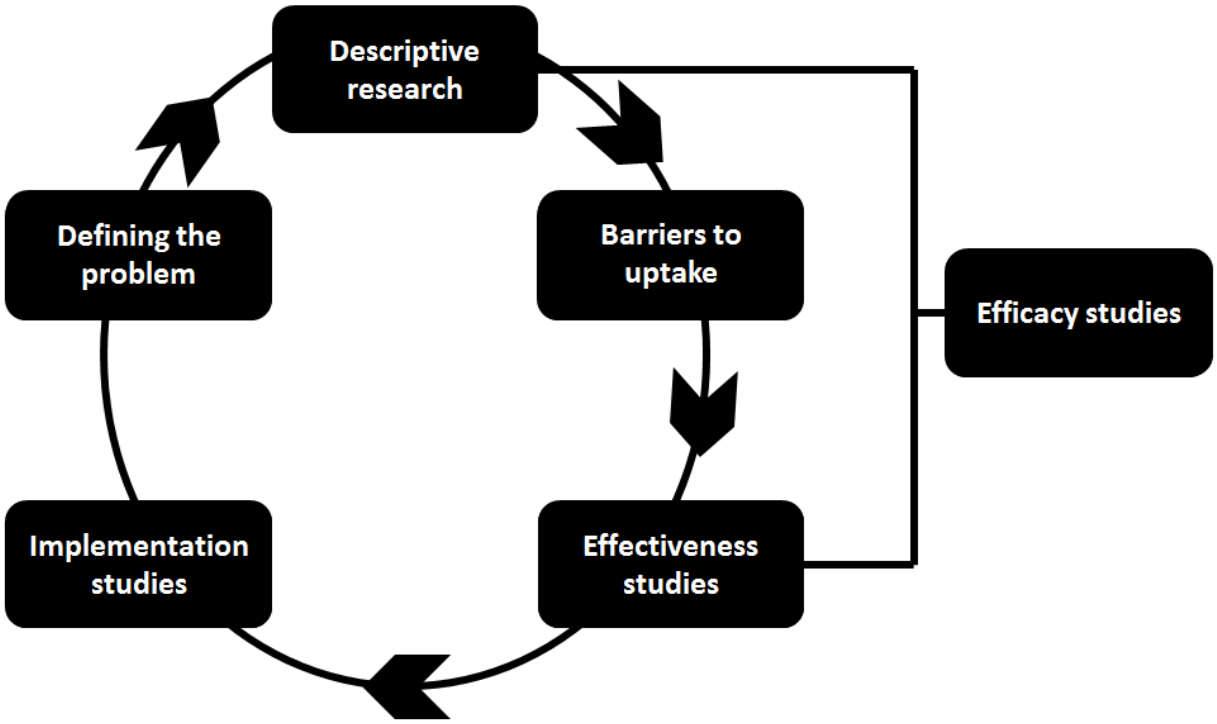

Figure 1.1 Schematic of a revised version of the Bishop (2008) applied research model. The model was developed to illustrate the crucial steps related to performing soccer related research projects (adapted from Drust & Green, 2013).

Alan McCall and colleagues asked 44 practitioners working worldwide at professional soccer clubs their perceptions of non-contact injury risk factors, the screening tests used to detect potential injuries, and the injury-prevention exercises applied at their club (McCall et al., 2014). Furthermore, McCall et al., (2015) used an online survey to determine the injury prevention strategies used, and the challenges faced by, physicians working for the 32 international soccer teams competing at the FIFA 2014 World Cup in Brazil. Gathering this type of information is useful as injuries have a negative impact on successful team performance (Hagglund et al., 2013), the short- and long-term health of players (Drawer and Fuller, 2001; McCall et al., 2015), and creates a large financial burden (Ekstrand, 2013).

Therefore it is clear that research of a qualitative nature allows for future ecologically valid research designs, education of coaches and players, and also has a potential influence on governing body policy. However, this type of research has yet to be conducted in relation to ET. Therefore, there is scope to develop an understanding of the perceptions and consequences of ET for applied practitioners, and the factors that hinder applied practice and intervention use. This would subsequently allow for the design of studies to investigate the efficacy of interventions while taking into account the transferability of the findings to an applied setting. Such information would provide practitioners with practical advice that supplements more traditional approaches (e.g., match analyses and actual and simulated soccer-match play protocols) for the preparation and recovery of players who may be exposed to an ET period.

1.2 MATCH ANALYSIS

The discipline of performance analysis (PA) in sport, particularly in soccer, has developed greatly in the past 10-15 years (McKenzie & Cushion, 2013). Performance analysis departments at professional soccer clubs are now ubiquitous, particularly at the elite level, with players and staff acknowledging its value when feeding information both forward to players and back to coaches (Drust, 2010). The use of PA in soccer research originates in the 1960's and 1970's by pioneers like Reep & Benjamin (1968) and Reilly & Thomas (1976). Early work such as this utilised manual hand-written notational analysis techniques to derive the demands of match-play such as the frequency of movement patterns and actions (i.e., sprints, passes, shots at goal). With the development of semi-automatic monitoring systems such as ProZone, researchers are now able to access large amounts of data in a much more time efficient manner. Indeed, a number of studies have been conducted using data derived from ProZone to profile the match demands of soccer (for a review see Castellano et al., 2014). With the introduction of wearable technology in soccer such as Global Positioning Systems (GPS), staff at professional clubs are now able to comprehensively monitor players. FIFA have recently permitted the use

of GPS during competitive match-play, allowing for more discrete actions such as accelerations and decelerations to be quantified accurately.

Due to the proliferation of technology and the number of researchers utilising it, the demands of 90 min of match-play are now well known. Players typically cover in excess of 10.5 km (in an intermittent manner, including forwards, backwards and sideways movements) during a match (Di Salvo et al., 2007; Andrzejewki et al., 2012; Barnes et al., 2014) with ~350m of that distance sprinting (>25 $km \cdot h^{-1}$; Barnes et al., 2014). Player also perform 600-1000 accelerations and 600-900 decelerations (>1 $m \cdot s^{-2}$; Akenhead et al., 2013; Russell et al., 2014). However, despite the existence of a large body of literature using technologies to quantify 90 min of soccer, there is a paucity of data regarding matches that are 120 min in duration (i.e., require ET). Due to the intermittent nature of soccer, maintaining physical performance throughout match-play is a fundamental aspect of overall match performance (Reilly et al., 2008). Therefore assessing physical performance parameters during ET allows for a better understanding of the demands of this period of play.

Only two investigations on the physical demands of ET have been published (Lago-Penas et al., 2015; Russell et al., 2015b). Using FIFA's database of physical performance data, Lago-Penas et al., (2015) examined seven matches from the 2014 FIFA World Cup that required ET. Total distance covered and distances covered at low (≤11.0 $km \cdot h^{-1}$), medium (11.1-14.0 $km \cdot h^{-1}$) and high (≥14.1 $km \cdot h^{-1}$) speeds were significantly lower in ET compared to the first 45 min of the match. Top speed was greater during the first 45 min compared to ET, and maximal running speed was lower in ET compared to both the first and second halves, with concomitant increases in the time spent in low intensity activities during ET. Furthermore, while observing five professional players wearing GPS units during a English Premier League reserve match, Russell et al., (2015) detected reductions in total distance covered, high-intensity distance covered, and the number of sprints, accelerations, and decelerations in the last 15 min of ET compared to the last 15 min of normal time (i.e., 76-90 min). Due to the small number of players/matches, the inherent match-to-match variability that exists during actual match-play (Gregson et al., 2010), and the aforementioned authors not taking into factors such as team tactics (Paul et al., 2015) and self-pacing strategies (Waldron & Highton, 2014), caution should be

taken in the interpretation of these results. As it appears ET elicits differential responses to those observed during 90 min, further work quantifying the demands of ET is required; particularly with respect to technical or skilled actions.

1.3 TECHNICAL PERFORMANCE DURING SOCCER MATCH-PLAY

Physical performance is a crucial factor related to match success, however; it is only one of a number of discriminating factors involved in successful performance. Another is skill (herein known as technical) performance. The importance of technical proficiency is a discriminating factor in match success (Lago-Penas et al., 2010); with teams finishing highest in the English Premier League completing the most successful passes (Bradley et al., 2015). Moreover, number of passes and pass completion rates have been associated with team success in other leagues (Lago-Peñas & Lago-Ballesteros, 2011; Castellano et al., 2012; Lago-Ballesteros et al., 2012; Collet, 2013). The aim of soccer is to score more goals than the opposition team; therefore the ability to shoot is an integral skill (Ali et al., 2007). Furthermore, the ability to dribble and control a ball is part of the fundamental skillset of soccer players (Reilly & Holmes, 1983). As such, executing a successful pass, dribbling with control and speed, or shooting accurately, will likely contribute to the outcome of a match (Stone & Oliver, 2009).

As soccer matches can be considered as stochastic, dynamic events (Liu et al., 2015), extrinsic factors such as league level, match location, quality of opposition, score line, and ball possession all influence technical performances (Taylor et al., 2008; Dellal et al., 2011; Lago-Penas & Lago-Ballesteros, 2011; Bradley et al., 2013). Furthermore, there is evidence that shows the frequency of technical performance parameters change over time (Barnes et al., 2014; Bradley et al., 2015). Barnes et al., (2014) observed more passes and dribbles and less final third entries in the 2012/13 English Premier League season compared to the 2006/07 season. As such, when interpreting data from empirical observations, readers should be cognisant of the evolving demands of match-play. Nevertheless, a number of authors have profiled the transient change in technical performance during match-play.

Seminal work by Rampinini et al., (2009) observed significant declines in involvements with the ball, and the number of successful short passes in the second half of Italian Serie A matches compared to the first half. Furthermore, Carling & Dupont (2010) observed reductions in the number of completed passes and ball possessions in the last five min of a match compared to both the first five min and a mean score of all other five min periods by 11 elite soccer players playing for a club in the highest league in France. The two aforementioned study's findings were corroborated by Russell et al., (2013), who observed significant reductions in the number of possessions and ball distributions (i.e., passing) when comparing the first half of English Championship matches to the second half; and the last 15 min compared to the first 15 min. As declines in some aspects of technical performance have been observed in the latter stages of 90 min matches, it is plausible that further changes occur in ET. However, no data is currently available examining the technical responses during both simulated and actual match-play that requires ET and so this supposition remains to be investigated.

1.4 PERFORMANCE RESPONSES TO SOCCER-SPECIFIC EXERCISE

1.4.1 Sprinting

Due to the high-intensity intermittent nature of soccer, players are required to perform both short and long sprints throughout match-play. Data from match-play suggests players perform approximately 17-30 sprints in a 90 min match (Di Salvo et al., 2009; Ingebrigtsen et al., 2014; Russell et al., 2014; Bradley et al., 2015; Schimpchen et al., 2016). Although the traditional notion of players performing repeated bouts of sprinting (i.e., three sprints < 30 sec) during matches has been challenged (Schimpchen et al., 2016), it is clear that players are required to perform isolated sprinting actions throughout exercise (Akenhead et al., 2013; Russell et al., 2014). Data from both actual match-play and simulations suggest players cover less distance sprinting and are not able to sprint as fast in the second half vs. the first half of soccer-specific exercise (Mohr et al., 2003; Di Salvo et al., 2009; Carling et al., 2011; Akenhead et al., 2013; Aldous et al., 2014; Russell et al., 2014). Therefore, it could be hypothesised that further decrements are observed during ET.

1.4.2 Jumping

A parameter used to measure acute fatigue during soccer-specific exercise is jumping performance. Changes in jump height may be indicative of modulations in neuromuscular function during exercise (Robineau et al., 2012; de Hoyo et al., 2016). As such, authors have incorporated different jumping techniques (predominately vertical jumps, squat jumps and countermovement jumps) into study designs. Results from both simulated and actual-match play remain equivocal, with some authors observing significant decrements in jump performance immediately following a match (Ispirlidis et al., 2008; Oliver et al., 2008; Magalhaes et al., 2010; Robineau et al., 2012; de Hoyo et al., 2016) and some detecting no changes (Thorlund et al., 2009; Stone et al., 2016). No studies to date have assessed jump performance at 90 min and then at 120 min. An assessment of this temporal change may give an indication of the manifestation of fatigue during ET. Russell et al., (2015b) observed depressed jump heights 24 and 48 hours following a competitive match requiring ET, however; they did not measure jump performance immediately post-match.

1.4.3 Technical performance

Not only are measures of physical performance important to soccer, but as mentioned previously, monitoring changes in technical performance (i.e., skill execution) is also pertinent. Three major technical components measured during actual and simulated match-play are dribbling, shooting, and passing.

1.4.3.1 Dribbling

To date, very few studies have implemented dribbling tasks or measured dribbling performance during matches, which is surprising considering the importance of dribbling in match success and discriminating between low- and high-level players (Stone & Oliver, 2009; Deprez et al., 2014). Most authors who have measured dribbling performance during 90 min of soccer-specific exercise have observed no decrements in time to complete dribble tasks or dribble precision (Currell et al., 2009; Russell et al., 2011a). Furthermore, no changes in dribbling performance (defined as number of situations where a player tries to

overcome another player with the ball in possession) were observed between the first and second half of 416 Italian Serie A matches (Rampinini et al., 2009).

1.4.3.2 Shooting

The ability to shoot, and therefore score goals is the most important and valued skill in soccer (Ali, 2011). Data suggests shooting performance can be influenced by fatigue, with authors observing reductions in both shot speed and precision at 90 min compared to pre-exercise during simulated match-play (Ali et al., 2007; Russell et al., 2011a). Furthermore, changes in biomechanics of the lower limbs during a 90 min Loughborough Intermittent Shuttle Test (LIST) protocol have been shown to cause reductions in shot velocity (Kellis et al., 2006). However, some authors have found no changes in shooting performance (i.e., total number of shots, shot precision and shot speed) during 90 min of simulated- (Bendiksen et al., 2012; Delextrat et al., 2013) and actual match-play (Rampinini et al., 2009).

1.4.3.3 Passing

Although data on the importance of high ball possession in soccer remains equivocal (Collet, 2013), the ability to maintain possession through accurate passing differentiates successful and unsuccessful teams (Rampinini et al., 2009; Adams et al., 2013). Passing is greatly influenced by extrinsic factors including playing formation (Bradley et al., 2011), score line (Paixao et al., 2015), and quality of opponent (Taylor et al., 2008). Nevertheless, successful short passing was found to be a contributing factor to winning matches in the group stage of the 2014 FIFA World Cup (Liu et al., 2015). Furthermore, longer passing sequences are more effective than shorter passing sequences in the build-up of attacks (Tenga et al., 2010), and passing accuracy scores can help discriminate between teams that score and concede goals (Redwood-Brown, 2008).

Temporal changes in indices of passing performance have been observed during both match-play (Rampinini et al., 2009; Paixao et al., 2015) and during simulations (Russell et al., 2010; Russell et al., 2011a), with decrements in the gross number of passes and number of successful short passes during the second half of matches (Rampinini et al., 2009), as well as a decline in passing

speed during a reliable passing test (Russell et al., 2010; Russell et al., 2011a). Furthermore, using the Loughborough Soccer Passing Test (LSPT), Rampinini et al., (2008) found perturbations in passing proficiency following high-intensity exercise designed to replicate the most intense 5 min period of match-play. Similar findings were observed by Lyons et al., (2006) who measured passing performance using the LSPT following one min of split squats at 90% of the individual's maximum capability. However, the ecological validity of the type and duration of the aforementioned physical exercise stimuli could be questioned. Indeed, other authors have observed no changes in passing performance using the LSPT during 90 min of soccer-specific exercise (Ali et al., 2007a; Ali & Williams, 2009). However, no study to date has assessed changes in technical performance in ET both during actual match-play or using specifically designed technical tasks implemented during simulated match-play. Therefore, there is scope to investigate transient changes in technical performance during 120 min of match-play as well as in a more controlled environment with less potential for confounding factors to have an influence. The utilisation of a controlled environment also allows a more robust investigation of the physiological responses during soccer-specific exercise, as match-play is not congruent with the use of blood sampling or gas analysis.

1.5 PHYSIOLOGICAL RESPONSES TO SOCCER-SPECIFIC EXERCISE

Soccer taxes both the aerobic and anaerobic energy systems due to its intermittent nature (Stolen et al., 2005). Heart rate data suggests players reach mean and peak heart rate values of 80-85% and 95-98% during match-play (Bangsbo et al., 2006; Russell et al., 2011a). Due to logistical constraints regarding the measurement of gas exchange during match-play, the precise intensity of exercise relative to $\dot{V}O_{2max}$ is difficult to interpret, however; indirect evidence suggests that average aerobic loading during match-play is approximately 70% of $\dot{V}O_{2max}$ (Ekblom, 1986; Mohr et al., 2004). Fatigue occurs transiently during match-play, as shown by reductions in physical performance (Mohr et al., 2003; Carling, 2013) and increases in goals scored (Reilly, 1997) during the last 15 min. However, the precise aetiology of this fatigue has yet to be delineated.

Changes in muscle metabolism and acid-base balance have been suggested as potential mechanisms for the multifactorial fatigue profile observed during 90 min of actual and simulated match-play. Due to regular brief intense actions performed during match-play, anaerobic energy turnover is high. Muscle glycogen progressively depletes during a match, with partial and complete depletion in specific muscle fibres (Krustrup et al., 2006). Furthermore, the build-up of metabolic by-products and ionic disturbances in the muscle interstitium may also be a contributing factor (Krustrup et al., 2006). However, only one study to date has assessed transient changes in acid-base balance during 90 min of simulated match-play (Russell & Kingsley, 2012). Although the authors observed significant decreases in blood pH and reductions in buffering capacity, the actual values observed were unlikely to be reflective of metabolic acidosis (i.e., blood pH and bicarbonate concentrations of 7.38 ± 0.01 units and 22.3 ± 0.6 mmol·l^{-1} during the second half).

Scandinavian researchers have used invasive biopsy techniques to assess changes in muscle pH, ammonia, lactate, and creatine phosphate during actual and simulated match-play (Krustrup et al., 2006; Bendiksen et al., 2012); however, no specific metabolite has been suggested as the cause of fatigue. Nonetheless, accumulation of intramuscular potassium and an associated electrical disturbance in the muscle cell may be a potential mechanism (Bangsbo et al., 2006). Furthermore, accretion of inorganic phosphate (P_i) in the muscle has been implicated as the major factor in tempered force production and increased fatigue during exercise (Allen & Westerblad, 2001; Westerblad et al., 2002; Allen & Trajanovska, 2012; Debold, 2012); however, changes in P_i have yet to be explored during soccer-specific exercise of any duration.

Utilisation of endogenous substrates alters during soccer-specific exercise, with muscle glycogen concentrations decreasing, and concentrations of markers of fatty acid breakdown and lipolysis (i.e., glycerol and free fatty acids; FFA) increasing in the second half of both actual and simulated match-play (McGregor et al., 1999; Krustrup et al., 2006; Clarke et al., 2008). These changes in substrate utilisation are likely due to both elevated adrenaline concentrations and dampened insulin concentrations. Elevated adrenaline concentrations both promote muscle glycogenolysis through its downstream activation of phosphorylase α (Watt et al., 2001), as well as activating adipose

tissue hormone-sensitive lipase and mediating adipocyte lipolysis (Vaughan & Steinberg, 1963). Lipolysis is further stimulated by dampened insulin concentrations as a match progresses, as insulin is a major inhibitor of lipolysis partly through its activation of Akt and suppression of protein kinase A (Choi et al., 2010).

Furthermore, blood lactate concentrations change transiently during soccer-specific exercise, with concentrations varying from 2-12 $mmol \cdot l^{-1}$, depending on the intensity of prior exercise. Lower blood lactate concentrations have been observed in the second half and latter stages of soccer-specific exercise compared to the first half (Krustrup et al., 2010; Bendiksen et al., 2012; Russell & Kingsley, 2012), thus providing further evidence for a shift from substrate level phosphorylation to fat oxidation as a match progresses. These changes are likely to be compensatory mechanisms for the progressive decline in muscle glycogen during soccer match-play so as to maintain blood glucose concentrations. However, these responses have not been assessed during an ET period, where it could be hypothesised that due to the prolonging of exercise, a further metabolic challenge is put upon players, with further decreases in muscle glycogen and greater energy utilisation from stored fat. Such changes are likely to impact on the ability to perform bouts of high-intensity running, which are crucial for successful soccer performance (Reilly, 1997; Faude et al., 2012).

With the advancement of technologies that quantify a large number of soccer-specific performance variables, it has become possible to conduct investigations using data collected from a high number of professional matches in a large cohort of players (MacKenzie & Cushion, 2013; Sarmento et al., 2014). Due to inherent match-to-match variation, large sample sizes are required to detect real systematic changes above the 'noise' of this variability. For example, Gregson et al., (2010) found CV's of 30.8 ± 11.2% and 16.2 ± 6.4% for total sprint distance and high-speed running distance, respectively. Furthermore, actual match-play is subject to a number of confounding factors such as environment, tactics, score line, and quality of opposition (Taylor et al., 2008; Dellal et al., 2011; Lago-Penas & Lago-Ballesteros, 2011; Bradley et al., 2013). Therefore, due to the restrictions associated with competitive match-

play, assessing physiological changes (i.e., heart rate, blood sampling) is impractical, and alternative methods have been sought.

Due to the aforementioned limiting factors, a number of research groups have developed simulations of soccer match-play (for a list see Table 1.1). These have been constructed to provide an exercise stimulus similar to what would be encountered during actual match-play but with greater experimental control and the ability to analyse physiological and metabolic changes. Two categories of simulations have been created: ones which are conducted on a treadmill (both motorised and non-motorised) and those that require field-based intermittent shuttle running.

1.6 SOCCER-SPECIFIC PROTOCOLS

1.6.1 Treadmill-based protocols

The first published work using a motorised treadmill to replicate the demands of match-play was by Abt and colleagues (1998). However, the authors did not state the actual movement pattern used (i.e., speed thresholds or frequency of exercise-intensity change) and the exercise bout was only 60 min in duration, with a modified Zelenka performance test requiring the performance of dribbling and shooting tasks pre- and post-exercise (Zelenka et al., 1967). Therefore, the exercise stimulus is unlikely to be representative of actual match-play due to its short duration and skilled tasks only being performed before and after exercise instead of throughout.

A protocol designed based on the intensity and extent of match-specific activities collated by Reilly and Thomas (1976) during 51 professional matches was developed at Liverpool John Moores University (Drust et al., 2000). The protocol has subsequently been adapted by Clarke et al., (2008), to include 90 min of activity as opposed to 45 min. The adapted protocol requires participants to complete two 45 min halves of intermittent exercise, with each half consisting of three 15 min bouts of identical intermittent activity, with speed of movement ranging from walking at 4 $km \cdot h^{-1}$ to sprinting at 19 $km \cdot h^{-1}$. A similar treadmill-based protocol has been developed by Page et al., (2015), however; their protocol integrated backwards running and a higher sprint speed (25 $km \cdot h^{-1}$).

Despite these authors demonstrating a similar mechanical load is elicited during the protocol compared to match-play, players are unlikely to reach their actual maximum speeds. Indeed, it is common for professional players in the English Premier League to reach speeds in excess of 30 $km \cdot h^{-1}$, with some players attaining speeds above 35 $km \cdot h^{-1}$ (www.opta.com).

To try and circumnavigate issues regarding attainable speeds and maximal running capability, a number of non-motorised treadmill based protocols have been developed (see Table 1.1). These include the intermittent shuttle performance test (iPST), the reliability and validity of which has been examined (Aldous et al., 2014). The iSPT utilises individualised speed thresholds with changes in variables such as high-speed running distance not being influenced by the aforementioned extrinsic factors. However, despite the apparent benefits of using a non-motorised treadmill, ball dribbling, backwards movements, and changes of direction are not implementable. As these factors have been shown to elicit a larger energy cost than compared to when no ball is present (Reilly & Ball, 1984) or when exercise is of a unidirectional nature (Reilly, 1997; Stevens et al., 2015); inclusion of these actions whilst also allowing players to produce maximum speeds may more closely represent match-play.

Table 1.1 A brief summary of studies using novel soccer-specific protocols

Reference	Protocol Type	Protocol Duration	Protocol Details
Abt et al., (1998)	Motorised treadmill	60 min	Intermittent exercise and modified Zelenka functional performance test pre- and post-exercise (Zelenka et al., 1967)
Bishop et al., (1999)	Field-based	2 x 45 min halves with 15 min passive half-time period	Intermittent exercise protocol incorporating ball dribbling
Drust et al., (2000)	Motorised treadmill	2 x 45 min halves and a 15 min passive half-time period	'Drust protocol': intermittent exercise (speeds ranging from 0 $km \cdot h^{-1}$ (standing) to 19 $km \cdot h^{-1}$ (sprinting) at 0% gradient)
Nicholas et al., (2000)	Field-based	90 min followed by a run to volitional exhaustion	'Loughborough Intermittent Shuttle Test' (LIST)
Abt et al., (2003)	Non-motorised treadmill	2 x 45 min halves with 15 min passive half-time period	-
Edwards et al., (2003)	Field-based	3 x 15 min periods separated by 3 min break + 10 min period	-
Thatcher & Batterham (2003)	Non-motorised treadmill	2 x 45 min halves with passive half-time period	Treadmill set at 2% gradient
Kingsley et al., (2005)	Field-based	45 min and 30 min of an adapted LIST protocol separated by a 10 minute passive half-time period.	30 min period followed by Multi-Stage Fitness Test to exhaustion (Ramsbottom et al., 1988)
Oliver et al., (2007)	Non-motorised treadmill	3 x 14 min exercise bouts interspersed with 3 min passive rest	-
Lovell et al., (2008)	Field-based	2 x 45 min halves with 15 min passive half-time period	'Soccer-Specific Aerobic Field Test' (SAFT90)

Reference	Protocol Type	Protocol Duration	Protocol Details
Sirotic & Coutts (2008)	Non-motorised treadmill	Maximal sprint speed test followed by a 30 min intermittent exercise bout	-
Currell et al., (2009)	Field-based	2 x 45 min halves with 15 min passive half-time period	Based on Ekblom (1989) field test. Incorporates agility, dribbling, kicking and heading tests
Williams et al., (2010)	Field-based	2 x 45 min halves with 15 min passive half-time period	'Ball-Sport Endurance and Sprint Test' (BEAST90): incorporates a ball shooting task and vertical jumps
Russell et al., (2011)	Field-based	2 x 45 min halves with 15 min passive half-time period	'Soccer Match Simulation' (SMS): incorporates ball dribbling, passing and shooting tasks
Bendiksen et al., (2012)	Field-based	2 x 45 min halves with 15 min passive half-time period	'Copenhagen Soccer Performance Test': incorporates ball dribbling, passing and shooting tasks
Aldous et al., (2014)	Non-motorised treadmill	2 x 45 min halves with 15 min passive half-time period	'Intermittent Soccer Performance Test' (iSPT)
Page et al., (2015)	Motorised treadmill	2 x 45 min halves and a 15 min passive half-time period	Speeds ranging from 0 $km \cdot h^{-1}$ (standing) to 25 $km \cdot h^{-1}$ (sprinting) at a range of gradients (1% - 2.5%)
Smith et al., (2015)	Non-motorised treadmill	45 min	-
Tofari et al., (2015)	Non-motorised treadmill	30 min	-

1.6.2 Field-based intermittent shuttle-running simulations

The use of protocols requiring intermittent shuttle running, typically on court-like surfaces is also popular, with a number being developed (see Table 1.1). The most commonly used is the LIST, developed by Nicholas et al., (1995) and further adapted to better replicate soccer match-play (Nicholas et al., 2000). Briefly, the LIST requires participants to complete six 15-min blocks of exercise, interspersed with four min rest periods. Each block consists of repeated cycles of walking, jogging, running and sprinting. However, despite being purported as a soccer-specific protocol, the LIST does not implement a 15 min half-time period, nor does it incorporate technical actions. The LIST, as well as other protocols, has been adapted to include isolated soccer skills (Ali et al., 2007b; Ali & Williams, 2009; Currell et al., 2009; Stone & Oliver, 2009). For example, Ali and Williams (2009) incorporated the LSPT during a 90 min LIST and Currell et al., (2009) included a kicking task in an adapted version of the field test designed by Ekblom (1989). However, the use of criterion and time-based measures in these studies lack some ecological validity as they are dependent on the scoring criteria assigned, and measuring only the time to complete a task is an incomplete representation of the skill executed (i.e., passing accuracy) (Russell et al., 2010).

With these limitations in mind, the LIST has been subsequently adapted to create more ecologically valid versions, with the inclusion of a half-time period and technical actions with applicable outcome measures. These include the Soccer Match Simulation (SMS; Russell et al., 2011b). The SMS incorporates dribbling, passing, and shooting tasks (see Figure 1.2) with measures of speed (e.g., shot speed), precision (e.g., distance between ball and cone when dribbling), and success (e.g., number of successful shots on target) as measures of performance. Furthermore, the SMS incorporates lateral and backwards movements, in addition to frequent changes of direction. The SMS and the constituent technical components have been shown to be both reliable (Russell et al., 2010; Russell et al., 2011a) and valid in the same group of players (Russell et al., 2011a). The SMS has been successfully used previously to assess performance and physiological responses (Russell et al., 2011a; Russell & Kingsley, 2012) and the efficacy of nutritional interventions during 90 min of soccer-specific exercise (Russell et al., 2012; Kingsley et al., 2014).

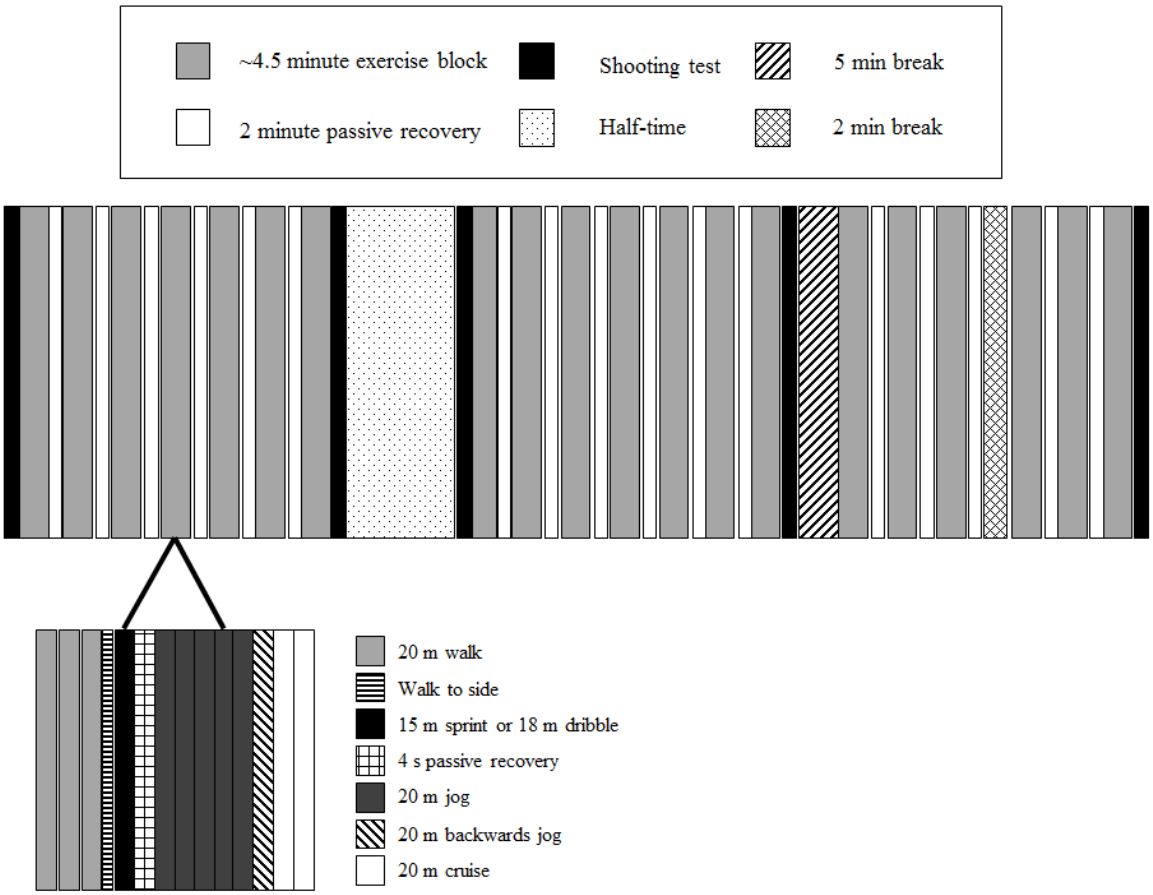

Figure 1.2 Schematic of the Soccer Match Simulation (SMS), developed by Russell et al., (2011b) and subsequently adapted to include ET.

However, the performance and physiological responses to 120 min of soccer-specific exercise remain unclear using such simulations despite some studies adding performance tests to the end of 90 min of exercise. Hulton et al., (2013) asked participants to perform a one km time trial immediately following a 90 min intermittent protocol on a motorised treadmill (Drust et al., 2000) as part of an investigation into the effect of fat and carbohydrate adjusted diets on performance. While investigating the effect of carbohydrate ingestion and pre-cooling on soccer-specific exercise, Clarke et al., (2011) included an additional three min performance test following a 90 min match simulation (Clarke et al., 2008). The participants were asked to run for three min at a pace that they felt they could sustain for 30 min. The rationale for this was to assess the influence of exercise-induced hyperthermia on the pacing strategies of players, with some consideration given to how this may impact performance during ET (Clarke et al., 2011). Furthermore, Foskett et al., (2008), asked participants to run to

volitional fatigue (except if they were unable to maintain the set intensity or their sprint times fell below 95% of their mean time for the first 45 min of exercise) following a 90 min LIST protocol to investigate the effect of carbohydrate-electrolyte beverages on performance. These post-90 min exercise models are probably more reflective of added time (i.e., the additional time referees include at the end of matches to account for injuries, substitutions and other stoppages in play) as they did not specifically incorporate a set 30 min ET period requiring the performance of soccer-specific actions (i.e., also including technical performance). As such, there is scope to investigate the performance and physiological responses to 120 min of simulated soccer match-play, while also assessing the reliability of these responses.

1.7 USING NON-SOCCER SPECIFIC PROLONGED MODALITIES OF EXERCISE TO INFER POTENTIAL RESPONSES TO EXTRA-TIME

Although no investigations currently exist detailing the physiological responses during ET, there is work profiling responses to other exercise modalities (i.e., cycling and running) across 120 min of exercise (e.g., Reilly & Lewis, 1985; Hargreaves et al., 1996; Matsui et al., 2011; Logan-Sprenger et al., 2013; Williams et al., 2015; Torrens et al., 2016). Asking participants to cycle for 2 hours at 65% $\dot{V}O_{2peak}$, Williams et al., (2015) observed reductions in blood glucose and increases in RPE from 90 to 120 min, but no changes in blood lactate. Logan-Sprenger et al., (2013) also asked participants to cycle for 120 min, whilst undergoing continuous online gas analysis, muscle biopsies and venous blood sampling. Increases in circulating FFA and adrenaline concentrations, decreases in carbohydrate oxidation with a concomitant increase in fat oxidation, as well as significant reductions in muscle glycogen concentrations from 80 to 120 min were observed. This data is also supported by Torrens et al., (2016) who observed a decrease in Respiratory Exchange Ratio after 120 min of cycling compared to at 90 min.

Taken together, these findings indicate a shift in substrate utilisation towards predominately using fat as a fuel in the last 30-40 min of a 120 min exercise bout, which if translated to soccer, may have negative corollaries for high-intensity exercise performance. Furthermore, an elegant study by Matsui et al.,

(2011) using a murine model, established that during 120 min of treadmill exercise, reductions in blood glucose, muscle glycogen, and liver glycogen are strongly correlated with decrements in site-specific brain glycogen concentrations. These diminutions in brain glycogen were not observed at 30 or 60 min of exercise, highlighting that the prolonged nature of exercise may not only have deleterious effects on blood glucose but also endogenous fuel sources crucial to both physical and technical performance. Additionally, these authors observed associations between reductions in astrocytic glycogen and activation of monoamine metabolism, which theoretically may be a mechanism of central fatigue during prolonged periods of exercise. These findings, despite using non-soccer-specific exercise models (and in the case of Matsui and colleagues, non-human participants), could represent a potentially deleterious impact of a 30 min ET period on performance. Therefore using both actual and simulated match-play to delineate the factors that influence physiology and performance is warranted.

1.8 FACTORS MODULATING SOCCER-SPECIFIC PERFORMANCE

1.8.1 Mental fatigue

Although fatigue is a multifactorial phenomenon, studies have predominately assessed fatigue on a functional, neuromuscular or metabolic basis. However, team sports such as soccer may possibly induce greater stress on the brain than any other activity (other than military combat; Walsh, 2014), particularly due to the dynamic, stochastic nature of match-play and thus a requirement for constant vigilance and concentration (Coutts, 2016). Furthermore, there is a large requirement for efficient technical performance in soccer, necessitating optimal motor control and coordination between the brain, nervous system, and the exercising musculature. Therefore it is likely that players will encounter mental fatigue, which may explain some of the decrements in performance observed transiently during a match (Badin et al., 2016). Indeed, recent research has shown that experimentally induced mental fatigue has a detrimental impact on technical performance and decision making (Badin et al., 2016; Smith et al., 2016a; Smith et al., 2016b), as well as aspects of soccer-specific running performance (Smith et al., 2015; Smith et al., 2016a).

1.8.2 Hydration Status and Glycaemia

Research would suggest dehydration occurs during 90 min of soccer-specific exercise, indicated by decreases in body mass (Ostojic & Mazic, 2002) and increases in plasma osmolality and blood sodium concentrations (Kingsley et al., 2014). The deleterious impact of dehydration on performance has been shown, with decreases in both technical (McGregor et al., 1999) and physical (Edwards et al., 2007; Mohr et al., 2010) performances when in a dehydrated state. However, these findings are equivocal, with some authors demonstrating no influence of hydration status on performance (Ali et al., 2010; Owen et al., 2013). However, it is good practice for players to maintain euhydration when in training and playing matches (Shirreffs et al., 2006; Laitano et al., 2014). Although it would seem that when players follow an optimal routine they are able to avoid dehydration-associated decrements in performance (Russell et al., 2011) an ET period has the potential to further impact hydration status due to the elongated exercise stimulus. However, the exact changes that occur have yet to be investigated.

A reduction in blood glucose concentrations has been proposed as a mechanism for impaired physical and cognitive function, and a potential factor for reduced soccer-specific performances (Winnick et al., 2005; Ali et al., 2007; Patterson & Gray, 2007), however; this theory has been disputed, as hypoglycaemia is rare during 90 min of soccer-specific exercise (Baker et al., 2015). However, hypoglycaemia has been observed following the ingestion of high glycaemic carbohydrate beverages during a passive half-time period (Russell et al., 2015c). Nevertheless, elevating blood glucose concentrations is associated with faster visual discrimination, fine motor speed, and psycho-motor speed; all factors related to successful soccer technical performance (Bandelow et al., 2011). Large bodies of evidence exist for the benefits of ergogenic aids that aim to ameliorate dehydration and reduced glucose concentrations, particularly the acute provision of carbohydrate. Indeed, the beneficial effects of carbohydrate on a number of exercise modalities and the performance of motor skill performance have been extensively reviewed (for contemporary reviews see Cermak & van Loon, 2013; Russell & Kingsley, 2014; Stellingwerff & Cox, 2014). Section 1.9 will specifically detail the influence of ergogenic aids

(predominately carbohydrate provision) on soccer-specific physical and technical performance.

1.9 NUTRITIONAL ERGOGENIC AIDS AND SOCCER PERFORMANCE

Due to the performance and physiological perturbations observed during simulated and actual soccer match-play (covered in more detail in sections 1.5 and 1.6), researchers have investigated the efficacy of particular nutritional ergogenic aids in attenuating these decrements. These include caffeine (Gant et al., 2010; Kingsley et al., 2014; Pettersen et al., 2014; Ali et al., 2015a; Ali et al., 2015b), sodium bicarbonate (Krustrup et al., 2015), nitrate (Wylie et al., 2013), tyrosine (Coull et al., 2015), and most popular of all, carbohydrate (Nicholas et al., 2005; Ali et al., 2007; Foskett et al., 2008; Phillips et al., 2010; Alghannam, 2011; Phillips et al., 2012; Russell & Kingsley, 2014; Pribyslavska et al., 2015). It is no surprise carbohydrate is the most popular of nutritional interventions, as diminished glycogen stores during soccer match-play has implications for both the integrity of the muscle, and the central nervous system (Krustrup et al., 2006; Rollo, 2014). Thus, the ability to preserve muscle glycogen and elevate blood glucose concentrations through nutritional means can have implications for motor control, skill execution, decision-making, and high-intensity intermittent exercise.

1.9.1 Carbohydrate and physical performance

The majority of evidence on the effect of carbohydrate ingestion on soccer-specific exercise capacity has been positive, with greater distance covered following soccer-specific protocols while ingesting carbohydrate versus placebo (Foskett et al., 2008; Phillips et al., 2010; Alghannam, 2011; Phillips et al., 2012). Indeed, Foskett et al., (2008) observed greater time to exhaustion when participants imbibed 3 $ml \cdot kg^{-1}$ BM of a 6.4% maltodextrin carbohydrate-electrolyte solution every 15 min during a 90 min LIST protocol and subsequent run to exhaustion. However, the variability and ecological validity of time to exhaustion tests not only in soccer but in athletic performance in general is questionable (Jeukendrup et al., 1996; Henegan et al., 2012). Furthermore, due to logistical constraints, soccer players can only practically ingest carbohydrate

of this amount at predetermined intervals during match-play (i.e., pre-match, half-time and in the 5 min prior to ET). Therefore the findings of these studies (i.e., Foskett et al., 2008; Phillips et al., 2010; Phillips et al., 2012) should be interpreted with caution, particularly as other authors have found no benefit of carbohydrate using a similar protocol but in a nutritional state that is more reflective of normal practice (i.e., provided breakfast 2 h pre-exercise; Goedecke et al., 2013).

The impact of acute carbohydrate intake on sprint performance during soccer-specific activity has mixed evidence, with some studies demonstrating small improvements in sprint time (Ali et al., 2007; Kingsley et al., 2014) and some reporting no benefit (Phillips et al., 2010; Phillips et al., 2012). The timing and dose of carbohydrate seems to be an influencing factor in the intervention effectiveness (Phillips et al., 2012; Russell & Kingsley, 2014). However, the effect of feeding carbohydrate at ecologically valid time points on physical performances during 120 min of soccer-specific exercise has yet to be investigated.

1.9.2 Carbohydrate and technical performance

Equivocal findings exist regarding the use of acute carbohydrate provision on changes in technical performance. As discussed previously, most studies have utilised soccer-specific protocols when investigating the efficacy of carbohydrate ingestion. Some researchers have found beneficial effects of carbohydrate on passing and shooting performance (Northcott et al., 1999; Ali et al.,2007a; Currell et al., 2009; Russell et al., 2012), and improved dribbling performance (Ostojic and Mazic, 2002; Currell et al., 2009) when compared to placebo. However, some authors have found no beneficial effects of carbohydrate on certain indices of technical performance (Zeederberg et al., 1996; Abbey & Rankin, 2009; Ali et al., 2007a; Ali & Williams, 2009). These variations in results may be due to a number of factors including level of player, nutritional status, and the sensitivity and validity of the tests used to measure performance. Nonetheless, carbohydrate provision is more likely to maintain technical performance when soccer players are in a fatigued state (i.e., in the latter stages of competition) as reductions in technical performance are not typically observed unless under conditions of fatigue (Russell & Kingsley, 2011; Baker et

al., 2015). Therefore there is scope to investigate the effect of carbohydrate ingestion following 90 min of soccer-specific exercise, prior to the performing of an ET period, where theoretically more fatigue would have manifested

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1.10 RESEARCH AIMS AND OBJECTIVES

The purpose of this chapter was: (1) provide information regarding the use of qualitative research methods to explore current issues in soccer, (2) synthesise information related to the performance and physiological demands of soccer-specific exercise and the factors that may modulate these factors (3) identify the effect of prolonged durations of exercise (i.e., 120 minutes) on performance and physiology, and (4) provide evidence for the use of nutritional interventions to improve soccer-specific performance. This approach was taken to allow for the identification of areas of required research regarding ET, based around the theoretical framework of Drust & Green (2013). In concordance with their framework, the review of the literature has identified the following key areas of research: (1) defining the problem of ET and potential barriers to uptake through descriptive (i.e., qualitative) research, (2) quantitatively assessing the influence of ET on performance and physiology through the use of performance analysis techniques and an analogue of soccer-match play, and (3) with decrements in performance expected, the effectiveness of a nutritional ergogenic strategy on performance and physiology during ET.

Using this information, the series of studies in this thesis were designed to specifically investigate the following:

(1) As research of a qualitative nature allows for future ecologically valid research designs, education of coaches and players, and also has a potential influence on governing body policy, the purpose of the first study was to use an online survey to (i) identify practitioners' perceptions of ET, their current practices, and possible barriers they face, and (ii) identify areas of future research that could inform subsequent investigations. Overall, this information would provide practitioners with practical advice for the preparation and recovery of players who may be exposed to an ET period.

(2) As practitioners identified ‘fatigue responses’ as the joint second most important research area, the aim of the second study was to retrospectively quantify transient changes in technical (i.e., skill) performance during professional soccer matches that required ET. This was actuated using a notational analysis technique to analyse videos of matches that were provided by performance analysis departments at professional clubs, as well as television broadcast recordings.

(3) The third study used an analogue of soccer match-play (i.e., Soccer Match Simulation; SMS) to provide a standardised environment that allowed the assessment of changes in physiological and performance responses throughout 120 min of match-play. A separate sub-investigation was also conducted to investigate the test-retest reliability of the protocol across 120 min to allow for robust conclusions to be made from the data.

(4) The practitioners surveyed in chapter 3 identified nutritional interventions as the most important future research area and we identified deleterious effects of ET on performance and physiology in chapters 5a and 5b. Therefore the aim of the final study was to investigate the effect of acute carbohydrate-electrolyte provision on performance during ET using the SMS. A sub-aim of this study was to detect changes in acid-base balance during the placebo arm of the design, to assess whether modulations in parameters associated with acid-base balance are responsible for decrements in performance.

Nota Bene: the chapters following the General Methods (i.e., chapters 3.0 to 6.0b) are the publications arising from this thesis and a chronology of the studies conducted.

2.0

GENERAL METHODS

2.0.1 OVERVIEW

This chapter describes the general methods and procedures employed during the main experiments contained within this thesis. Specific methods and procedures are also presented within the applicable chapters.

2.1 PARTICIPANTS AND STUDY APPROVAL

All of the studies involved human volunteers. Practitioners working in professional soccer completed the online survey in chapter 3. Video footage of professional soccer players was used for chapter 4. University-standard soccer players were used for chapters 5a and 5b. Players playing for an English Premier League academy were used for chapters 6a and 6b. Inclusion and exclusion criteria for each study are presented in the specific chapters.

Each study received ethical approval from the Health and Life Sciences ethics committee at Northumbria University. All participants were provided information both verbally and in written form to ensure they were aware of the purpose and requirements of the study. All participants provided written informed consent before participating in each study (Appendix 1). Specifics relating to informed consent are provided in the relevant chapter. All participants were also aware they were free to withdraw from each study without explanation.

2.2 STUDY DESIGN

For chapters 5a to 6b, full familiarisation trials were included to reduce the effects of trial order. Further details are provided in the relevant chapter. Chapter 6a employed a double-blind placebo controlled crossover design (more details provided within the chapter). All participants were requested to detail their dietary intake for 48 h prior to each trial during the studies detailed in chapters 5a to 6b. Energy intake and macronutrient breakdown was conducted using commercially available software (Microdiet, Downlee Systems Ltd., High Peak, UK for chapter 5a and Nutritics, Nutritics Ltd., Dublin, Ireland for chapters 5b to 6b; Appendix 2). This measure was put in place to ensure any changes between trials were not due to differences in pre-trial dietary intake. To further

control for dietary intake, participants were provided a standardised evening meal in chapter 5a. In chapters 5b to 6b participants were asked to consume the same evening meal the day before each trial. Furthermore, participants were provided a standardised breakfast on the day of each trial in all studies detailed in chapters 5a to 6b (further details provided in the relevant chapter). Participants were asked to refrain from strenuous physical activity prior to each main trial (specific details on time period provided in each chapter). This control was administered so as to remove the effect of prior physical activity on the results gathered from each study. Participants were asked to provide verbal confirmation that they had complied with this request.

2.3 ANTHROPOMETRY

In chapters 5a to 6b, the participant's mass and height were measured in accordance with the International Standards for Anthropometric Assessment. Body mass was determined using digital scales (model 876, Seca GmbH, Hamburg, Germany; sensitive to the nearest 0.1 kg) while the participants wore only shorts. Free standing height was determined using a portable stadiometer (model 213, Seca GmbH, Hamburg, Germany; to the nearest 0.001 m). The participants maintained an upright posture with the head positioned in the Frankfort plane, with their feet together and heels touching the base of the stadiometer while the head board was lowered to the vertex of the head.

2.4 NOTATIONAL ANALYSIS

In chapter 4, a notational analysis method was used to quantify changes in technical performance during actual professional soccer matches that required ET (i.e., had a duration of 120 min). Specific details related to this method are provided in chapter 4. Figure 2.1 illustrates the software used for analysis (Sportstec Gamebreaker; Sportstec, New South Wales, Australia).

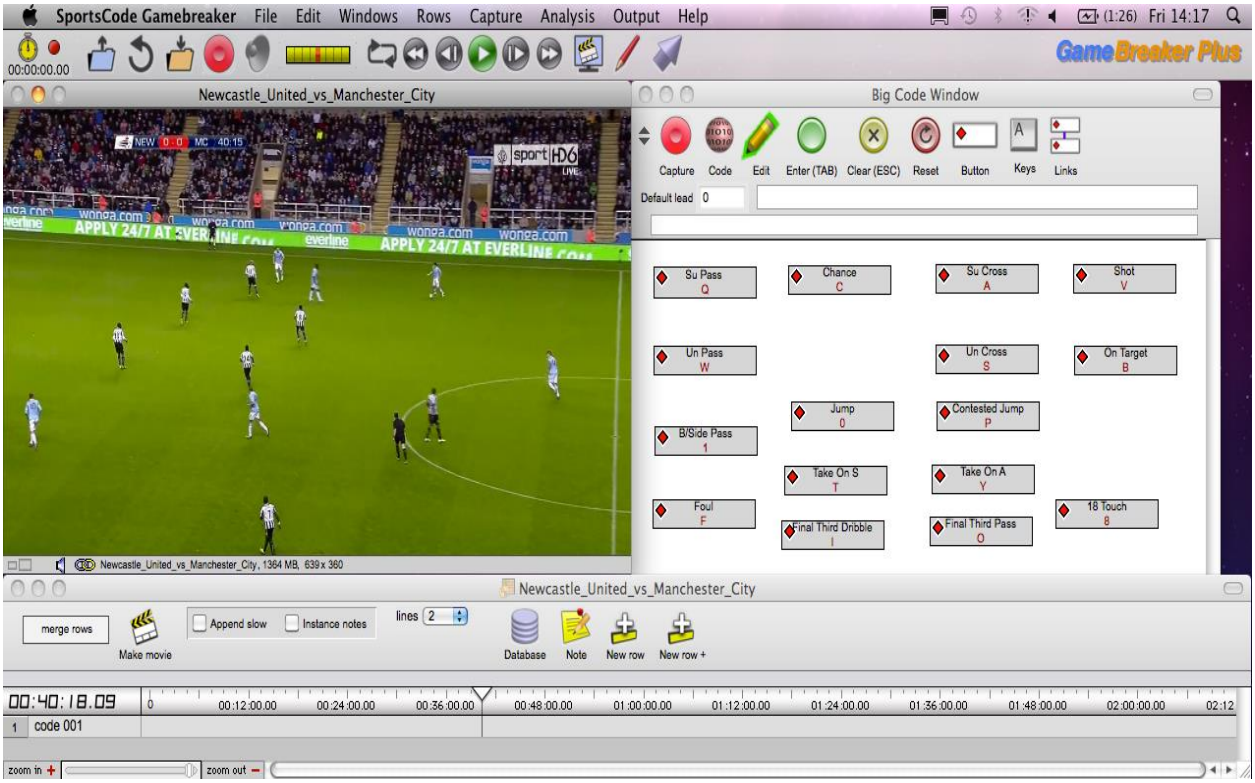

Figure 2.1 Screenshot of software used for notational analysis (chapter 4)

2.5 EXERCISE SIMULATION: SOCCER MATCH SIMULATION

Chapters 5a to 6b incorporate the SMS (Russell et al., 2011). Players either completed the protocol alone or were paired when possible according to estimated aerobic capacity (Multi-stage fitness test, MSFT; Ramsbottom et al., 1988) and completed two 45 min halves of intermittent activity that were separated by a 15 min recovery period (half-time). After a passive 5 min recovery period a 30 min ET period was also performed. Movements were dictated by audio signals on mp3 files that were specifically made for all player pairings and each participant alternated between sprinting and dribbling during each cycle. More specifically, exercise was made up of ~4.5 min blocks that consisted of three repeated cycles of three 20 m walks, one walk to the side, an alternating 15 m sprint or an 18 m dribble test, a four *s* passive recovery period, five 20 m jogs at a speed corresponding to 40% $\dot{V}O_{2max}$, one 20 m backwards jog at 40% $\dot{V}O_{2max}$, and two 20 m strides at 85% $\dot{V}O_{2max}$ (see Figure 1.2). A two min recovery period was completed after all blocks of exercise, where

participants gave subjective ratings (see section 2.7) and during some of the recovery periods, provided a blood sample (for more details see section 2.10). Seven blocks of intermittent exercise and skill testing were completed during each half of exercise, and six blocks were completed during ET. The participants covered a total distance of 14.4 km during the protocol.

2.6 PHYSICAL PERFORMANCE MEASURES PROCEDURES

As shown in Figure 2.2, jump height, repeated sprint ability and soccer shooting performance was assessed on five occasions (Performance Test, PT) throughout each main trial (i.e., pre-first half, post-first half, pre-second half, post-second half, post ET) in chapters 5a to 6b.

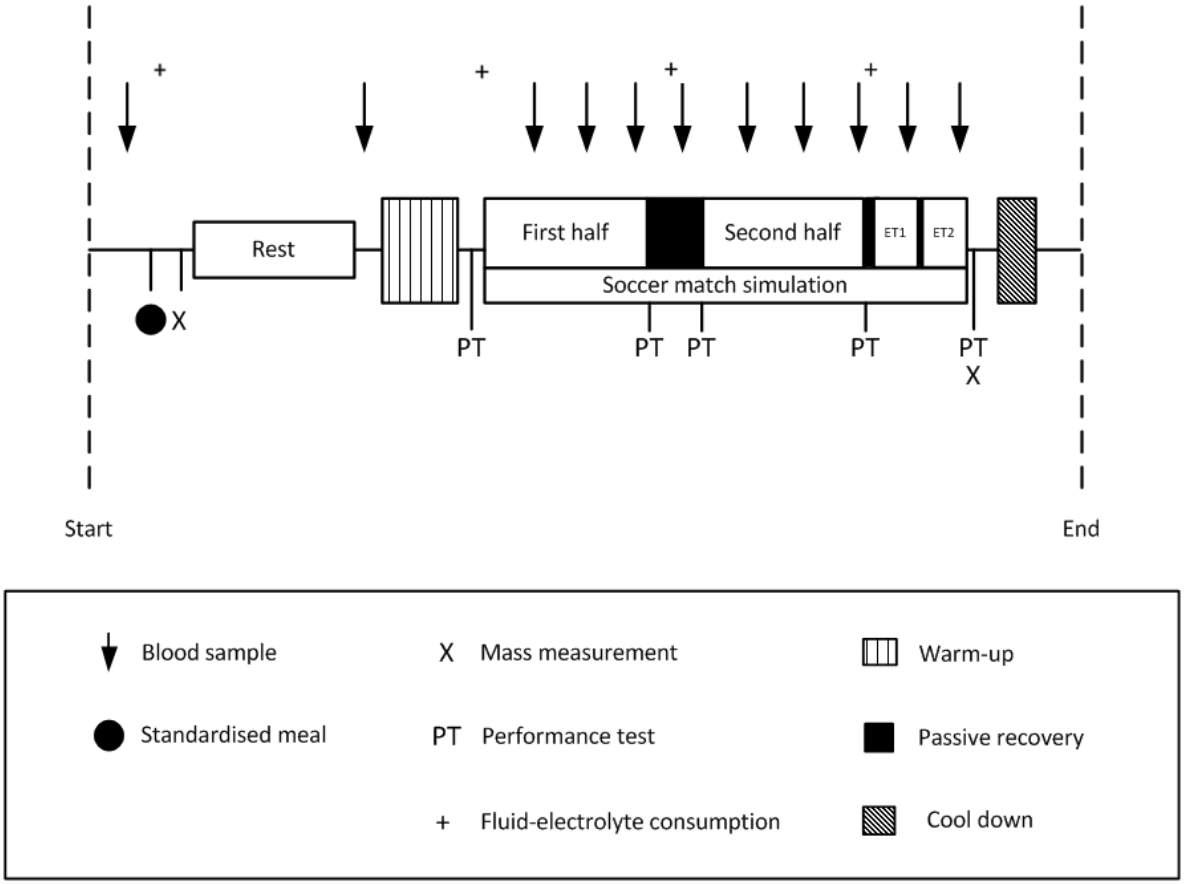

Figure 2.2 General overview of testing day procedures

2.6.1 Jump Height

In chapters 5a to 6b, countermovement jump (CMJ) height was determined during the PT using an optical measuring system (OptoJump Next, Microgate SRL, Bolzano, Italy). Participants began each repetition from a standing position and performed a preparatory crouching action before explosively jumping out of the dip for maximal height. Hands were isolated at the hips for the entire movement to eliminate any influence of arm swing. Participants performed three repetitions with 10 *s* of recovery between attempts. Jump height was measured to assess changes in lower body power output and neuromuscular fatigue during exercise.

2.6.2 Sprint Testing

For assessment of repeated sprint ability during the PT, participants performed three maximal 20 m sprints (30 m in chapters 6a and 6b), separated by a 25 *s* period of active recovery, during which the players returned to the starting line. Participants commenced each repetition from a standing start at a distance of 0.3 m behind the first timing gate (TC-Timing System; Brower Timing Systems, Utah, USA) and verbal encouragement was provided throughout each attempt. Furthermore, 15 m sprint performance was assessed throughout the SMS during alternate cycles of intermittent exercise (30 sprints performed in total). Sprint testing was conducted due to its particular relevance to soccer-specific exercise performance.

2.7 SUBJECTIVE RATINGS PROCEDURES

During studies detailed in chapters 5a to 6b, rating of perceived exertion (RPE; 6-20 scale; Borg, 1973; Appendix 3) was recorded at the end of each block. Abdominal discomfort (AD) was also measured at the same time (0-10 scale, Price et al., 2003; Appendix 4). Rating of perceived exertion was taken due to its sensitivity as a measure of fatigue perception (Eston & Williams, 1988). Abdominal discomfort was measured to assess the effect of exercise on gastrointestinal distress and also the nutritional intervention used in chapter 6.0a.

2.8 SKILLS TESTING PROCEDURES

Figure 2.3A illustrates the dribbling task implemented in chapters 5a to 6b. Figure 2.3B illustrates the shooting task implemented in chapter 5a.

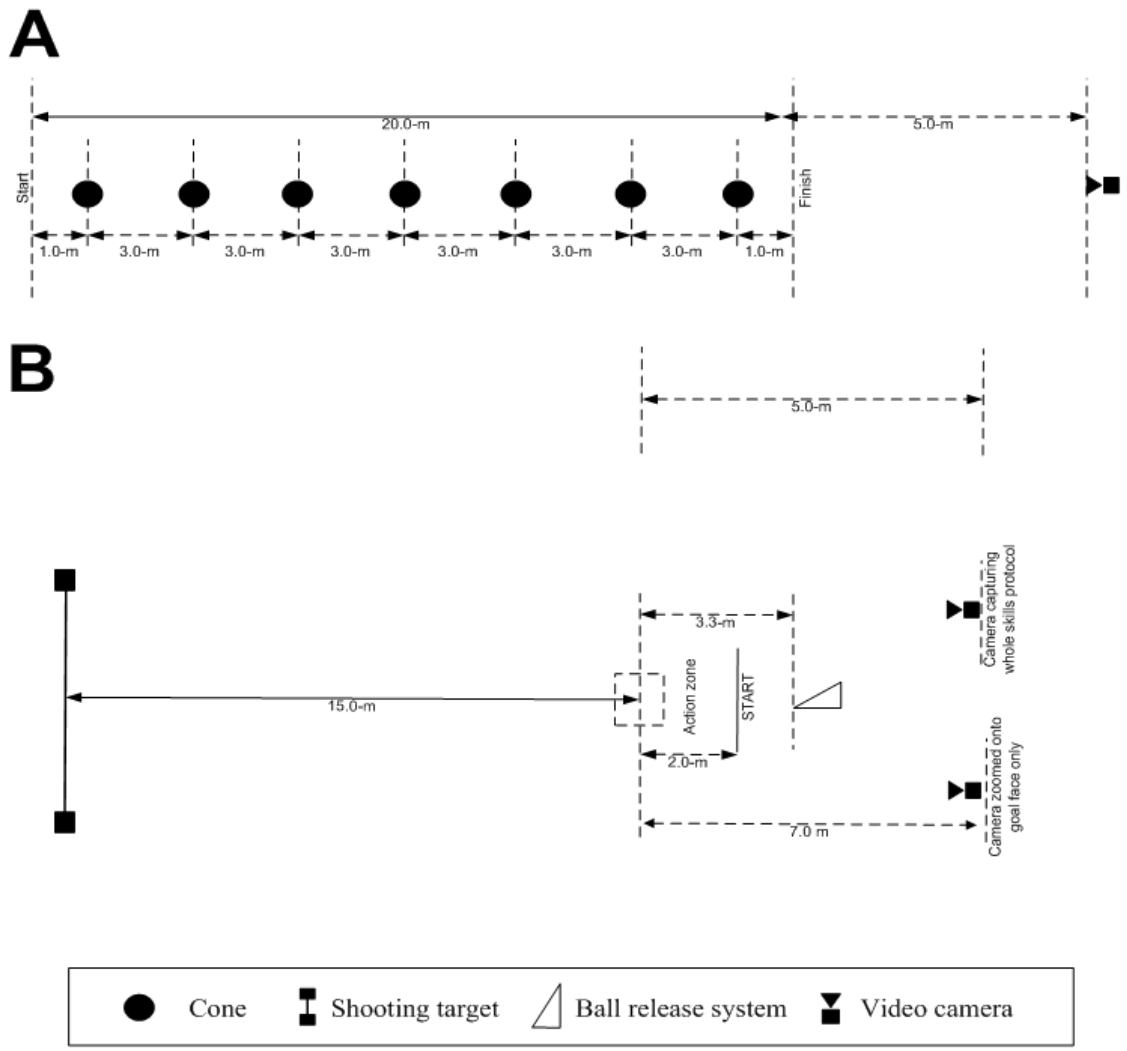

Figure 2.3 Schematic demonstrating the setup for the dribbling and shooting tasks.

2.8.1 Shooting

The shooting task was performed on an indoor sports hall surface at five time points during chapter 5a: pre-first half, post-first half, pre-second half, post-second half, post ET. Professional standard footballs (Mitre Promax: size 5; Mitre Sports, Finchley, UK) were released at a constant speed down a custom-

built ramp towards a 1.5 x 1.5 m square (action zone; indicated by yellow lines in Figure 2.4), where participants were instructed to kick the ball. The participants kicked towards one of four randomly determined targets. Consequently, the players were required to carry out visual searching and decision making during each attempt. Motion sensors on the ball release mechanism ensured that a delay of 0.64 s existed between target identification and the ball reaching the centre of the action zone. Previous work during the tests development found this to be the most appropriate time delay (M Russell, PhD thesis).

Shots were performed in bouts of four attempts with approximately 30 *s* of recovery separating each individual kick. Participants commenced the test from a standing start before jogging into the action zone when the ball was released. The shooting target was the size of a standard soccer goal (measuring 7.33 x 2.44 m). Four target lights were positioned 1.0 m horizontally inside each post and 0.5 m vertically inside the upper and lower edges of the goal (indicated by light blue circles in Figure 2.4). Targets were placed in the corners of the goal as this has been identified as optimal ball placement to beat a goalkeeper when shooting (Ali et al., 2007). Participants were instructed to kick the ball as accurately as possible at the illuminated target within the goal. To enhance ecological validity, no prior touches were allowed to control the ball (Olsen, 1988) and participants kicked the ball with their foot of choice.

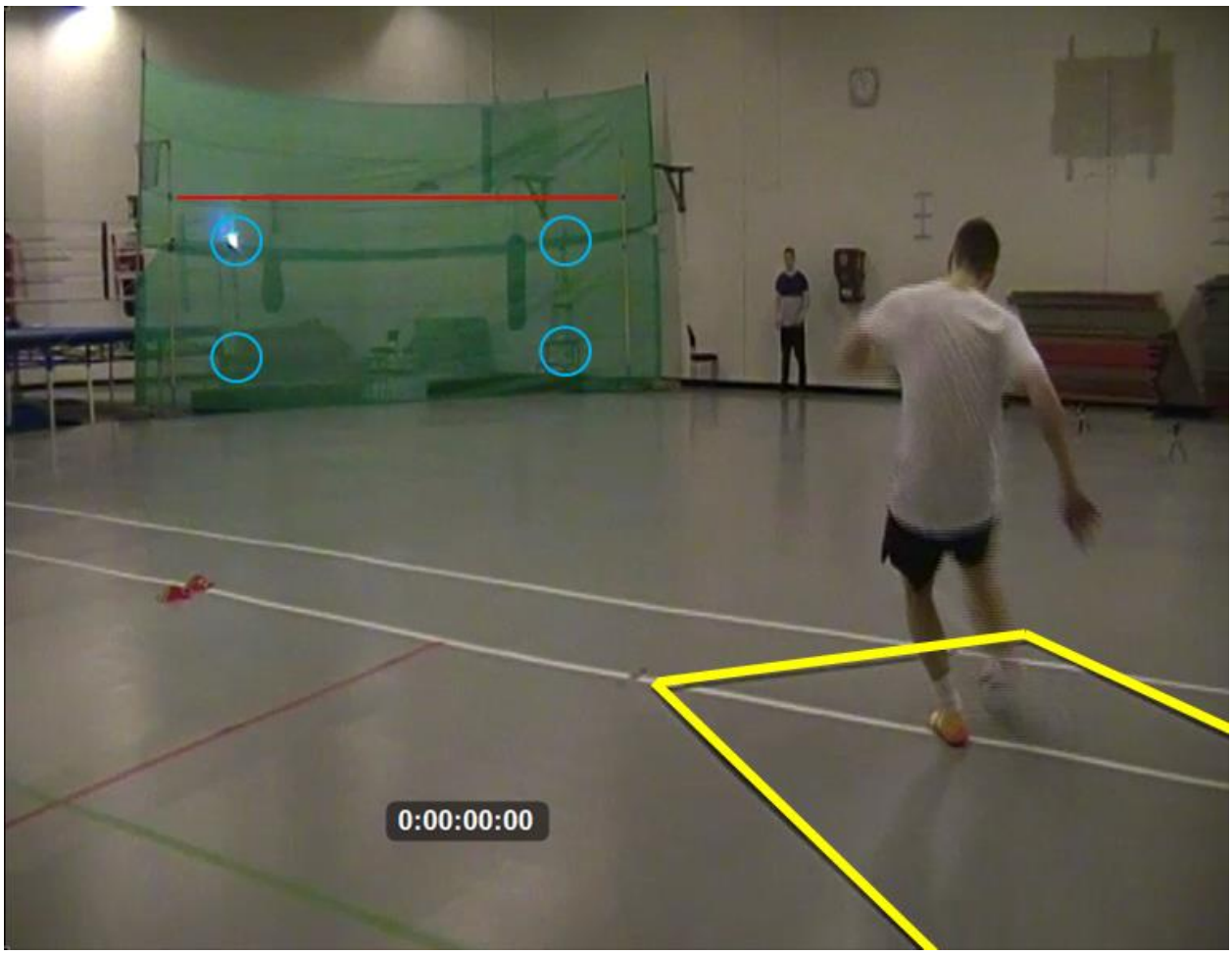

Figure 2.4 Screenshot of shooting task used in chapter 5a. Yellow lines indicate the action zone which the ball was fed into for the players to kick. Blue circles indicate the location of the four targets that were randomly determined during ball release.

2.8.1 Dribbling

The layout of the 18 m dribbling test included in the intermittent exercise blocks of the SMS is similar to that employed by McGregor et al., (1999) with start and finish lines placed 20 m apart (Figure 2.3). Cones two through seven were placed 3 m away from the preceding cone, and cones one and seven were 1 m away from each end of the course. Participants were required to dribble the ball as fast and as accurately as possible between all cones. Participants dribbled towards a video camera that was placed directly in line with the cones.

2.9 SKILLS TESTING ANALYSIS

Video footage of each skill performed during studies detailed in chapters 5a to 6b were captured onto digital memory cards using 50 Hz video cameras (Sony Ltd, UK) which were positioned as shown in Figure 2.3. Specific variables of speed, precision, and success were calculated for all skills *via* manual digitisation of the footage. The following measures were taken as shooting and dribbling are key skills that are intrinsically linked to soccer-specific performance.

2.9.1 Determination of ball speed

Average ball speeds were calculated for all skills using the distance-time relationship, where the time component was calculated using biomechanical analysis software (Kinovea v.0.8.15; Kinovea Org., France). In the case of shooting, distances covered were assumed to originate from the centre of the action zone and were calculated via Pythagoras' Law in conjunction with precision data from the respective targets. For dribbling, average ball speed was calculated using the known values of the length of the dribble course with the time difference between initial ball contact and completion of the required distance.

2.9.2 Determination of ball precision

Precision was determined at the frame corresponding to ball impact on the target (shooting; Figure 2.5), and at the frame where horizontal deviation from the cones was maximal (dribbling; Figure 2.6) by digitisation of video footage (Kinovea version 0.8.15; Kinovea Org., France). For all skills, precision represents the distance of the centre of the ball from the centre of the target. Image deformations were corrected for by modified direct linear transformation using known positions of calibration markers to calculate calibration constants.

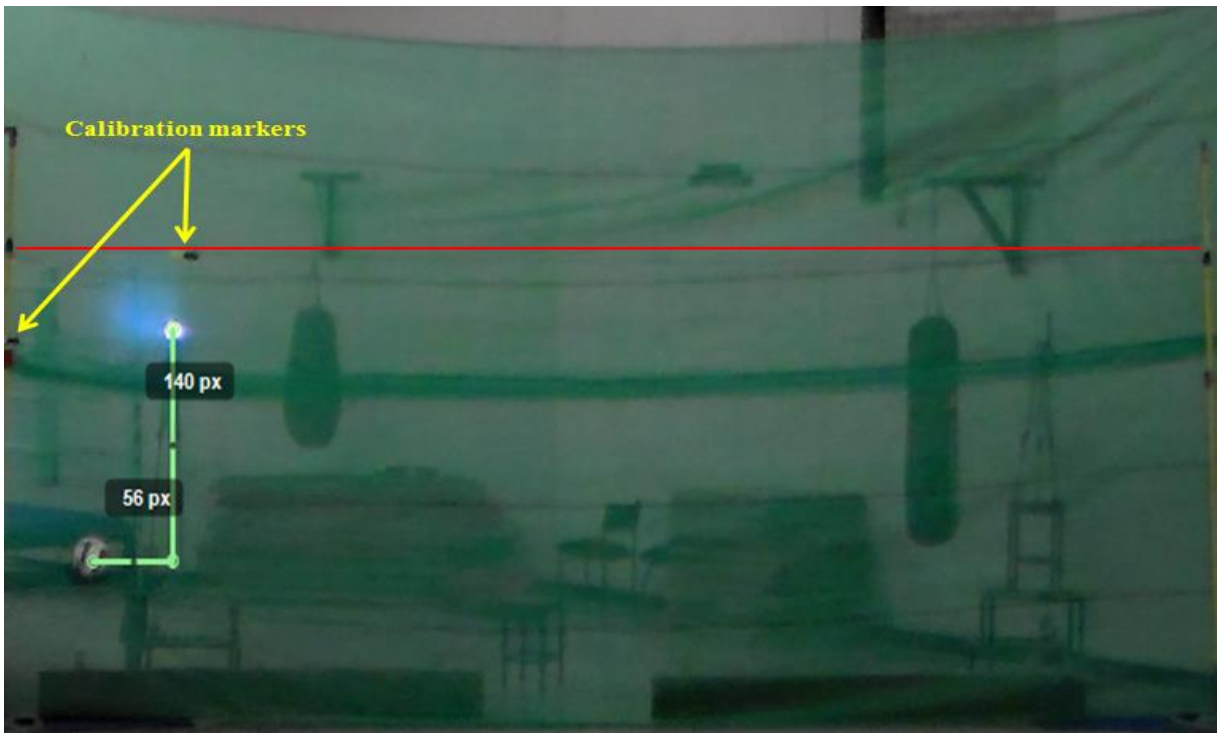

Figure 2.5 Digitised image of calculation of shooting precision (centre of the ball to centre of the target (light)

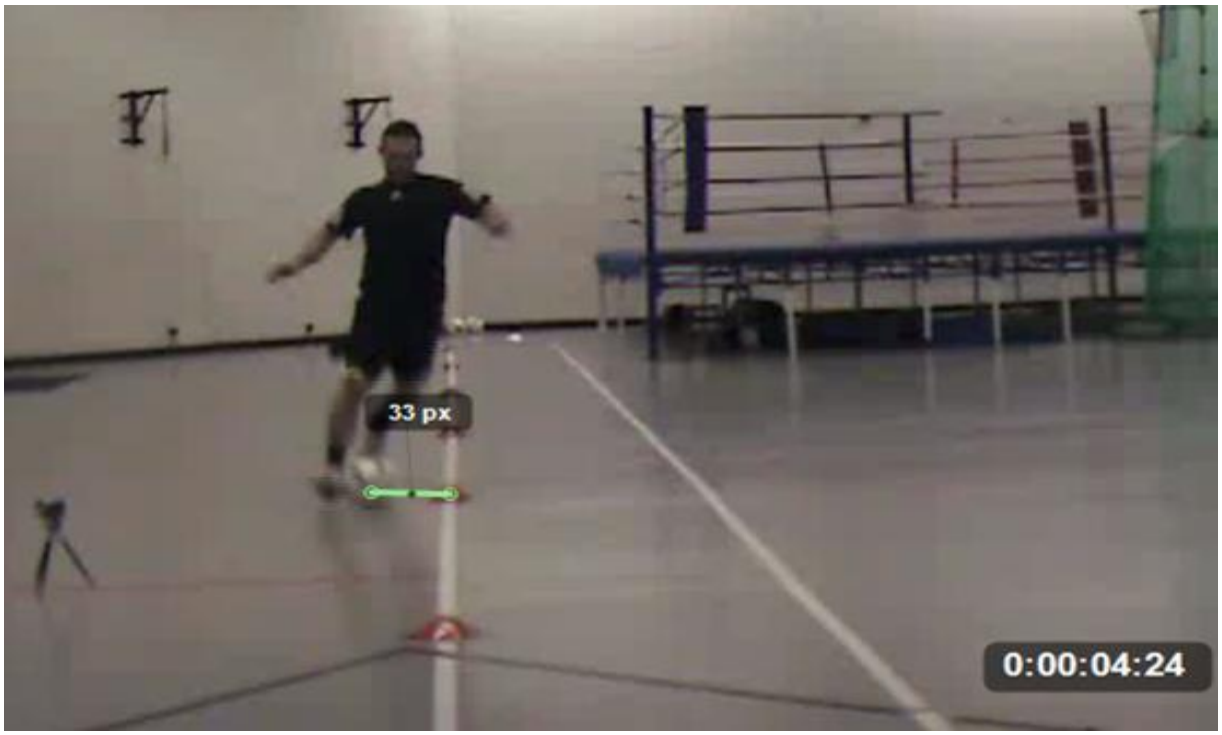

Figure 2.6 Digitised image of calculation of dribbling precision (centre of the ball to the centre of the cone)

2.9.3 Determination of success rate

Success in shooting was defined as those skills that were executed within the confines of the action zone and the ball impacted within the goal frame. Shooting success represents the percentage of shots that met this criterion. During dribbling, if a cone was touched by the ball or was not completed in the required direction, the cone was considered to be unsuccessfully negotiated. Success in dribbling represents the percentage of cones successfully completed.

2.10 BLOOD ANALYSES

In chapter 5a, blood was collected from an intravenous cannula inserted into a vein in the antecubital fossa. In chapter 5b, blood was collected using both fingertip and venepuncture techniques. For chapters 6a and 6b, blood was collected by fingertip puncture only. Further details can be found in the relevant chapter; this section provides specific information regarding the techniques used to analyse the blood, including the precision of the measurements.

2.10.1 Determination of blood glucose and lactate

In chapters 5a and 5b, blood glucose and lactate were measured using an enzymatic-amperometric method (Biosen C-Line+; EKF Diagnostics) using whole venous and capillary blood, respectively. The Biosen C-Line+ was calibrated before use using manufacturer provided calibration fluid. Manufacturer derived CV's for both glucose and lactate are 1.5%. In chapter 6a, blood glucose and lactate were measured using a blood gas analyser (GEM Premier 3000; Instrumentation Laboratory). Manufacturer day-to-day and total CV's are 2.2% and 2.9%, respectively for glucose and 4.7% and 4.9%, respectively for lactate. Blood glucose and lactate concentrations were measured to assess glycemia and substrate utilisation during exercise.

2.10.2 Determination of adrenaline, interleukin-6 (IL-6) and insulin using enzyme-linked immunosorbent assay (ELISA)

In chapter 5a, adrenaline, IL-6 and insulin concentrations were measured using an ELISA method. Insulin and IL-6 concentrations were also measured in chapter 5b. Adrenaline and IL-6 were measured due to their association with

muscle glycogen utilisation (Ball, 2015) and insulin concentrations for glycemia and substrate utilisation. For all ELISA's, standard curves were created using solutions containing known quantities of insulin, adrenaline, and IL-6 as provided by the manufacturer.

2.10.2.1 Quantification of insulin concentrations

Plasma samples were used for the quantitative determination of insulin using a commercially available kit (Insulin ELISA; IBL International GmBH, Hamburg, Germany). The kit is a solid phase ELISA based on the sandwich principle. The microtiter wells were coated with a monoclonal antibody directed towards a distinct antigenic site on the insulin molecule. An aliquot of plasma containing endogenous insulin (i.e., participants samples) was incubated in the coated well with enzyme conjugate, an anti-insulin antibody conjugated with Biotin. After incubation the unbound conjugate was washed off. Streptavidin Peroxidase Enzyme Complex was then bound to the biotin-anti-insulin antibody. The amount of bound complex is considered proportional to the concentration of insulin in the sample. Following the addition of substrate solution, the intensity of colour that developed was considered proportional to the concentration of insulin in the plasma sample. Manufacturer derived intra-assay and inter-assay variation is 1.8% and 2.9%, respectively.

2.10.2.2 Quantification of adrenaline concentrations

A solid phase ELISA based on the sandwich principle was used (Adrenalin ELISA; IBL International GmBH, Hamburg, Germany), using plasma. The wells were coated with a goat anti rabbit antibody. The added liquid antibody, directed towards an epitope of the adrenaline molecule was bound to the plate. The adrenaline in the sample was incubated in the coated well with enzyme conjugated second antibody (E-Ab), directed towards a different region of the adrenaline molecule. After a substrate reaction, the intensity of the developed colour was proportional to the amount of the adrenaline in the sample. Manufacturer derived intra-assay and inter-assay variation is 6.8% and 15.2%, respectively.

2.10.2.3 Quantification of IL-6 concentrations

An ELISA technique was used for the quantitative detection of IL-6 in plasma (Interleukin-6 ELISA; IBL International GmBH, Hamburg, Germany). An anti-human IL-6 coating antibody was absorbed onto the microwells. Plasma samples were then added to each microwell and the human IL-6 present in the sample was bound to antibodies that are absorbed to the microwells. A biotin-conjugated anti-human IL-6 antibody was then added which binds to the human IL-6 captured by the first antibody. Following incubation, a wash step was used to remove unbound biotin-conjugated anti-human IL-6 antibody. Streptavidin HRP was then added to allow bounding to the biotin-conjugated anti-human IL-6 antibody. Unbound streptavidin HRP was then removed during another wash step, with substrate solution consequently added to the wells, which is reactive with HRP. The intensity of the colour that developed in each microwell was used as a representative of the proportion of human IL-6 present. Manufacturer derived intra-assay and inter-assay variation is 3.4% and 5.2%, respectively.

2.10.3 Determination of glycerol and non-esterified fatty acids (NEFA) concentrations

In chapter 5a and 5b glycerol and NEFA concentrations were measured using commercially available kits on an automated clinical chemistry analyser using 50 µl of plasma (Randox Daytona^{+}; Randox Laboratories Ltd., Co. Antrim, UK). Briefly, once samples were loaded into the analyser and the appropriate tests programmed into the system, a probe measured the aliquot of sample that is subsequently inserted into a reaction vessel, where reagents are automatically added from an on-board refrigerated supply. On each run of the analyser, aliquots of solutions containing known quantities of NEFA and glycerol (as provided by the manufacturer) were also analysed and served as calibrators. Colorimetric testing was then used to determine the concentration of the metabolites. Manufacturer derived intra-run and inter-run variation is 0.9% and 2.6%, respectively for glycerol, and 1.2% and 4.7%, respectively for NEFA. Blood glycerol and NEFA concentrations were measured to assess the use of stored fat as a fuel during exercise.

2.10.4 Determination of potassium concentrations using atomic absorption spectrophotometry

Plasma potassium concentrations were determined in chapter 5a by atomic absorption spectrophotometry using 100 µl of heparinised plasma and a reference wavelength of 766.5 nm (PerkinElmer 3100 Atomic Absorption Spectrophotometer (AAS); PerkinElmer Inc., Massachusetts, USA). A 1:100 dilution of plasma samples was performed using deionised water prior to measurement in the AAS and then the value obtained was converted to actual potassium concentration using a standard curve generated prior to the analysis of samples using solutions containing known quantities of potassium. Potassium concentrations were determined as potassium accumulation may be indicative of fatigue during exercise (Krustrup et al., 2006).

2.10.5 Determination of creatine kinase (CK) concentrations

Creatine kinase (CK) concentrations were determined using absorption photometry on a Cobas 8000 modular analyser, a clinical chemistry platform (Cobas 8000; Roche Diagnostics; USA) at an external testing site (Royal Victoria Infirmary, Newcastle upon Tyne, UK). Intra-run and inter-run variation is 0.7% and 0.8%, respectively (Kim et al. 2014). Changes in CK may be indicative of muscle damage during exercise (Brancaccio et al., 2007).

2.10.6 Determination of bicarbonate (HCO^{3-}), calcium (Ca^{2+}), potassium (K^{+}) and sodium concentrations (Na^{+}); and pH values using the GEM Premier 3000 analyser

In chapters 6a and 6b 170 µL of whole blood was analysed immediately using a blood gas analyser (GEM Premier 3000, Instrumentation Laboratory, UK). The central component to the analyser is a sensor card which provides a low volume, gas tight chamber in which the blood sample is presented to specific sensors that are capable of analysing pH, Na^{+}, K^{+}, Ca^{2+}. The system was calibrated on the morning of each testing session using solutions provided by the manufacturer. Manufacturer day-to-day and total CV's are 0.5% and 0.6%, respectively for Na^{+}, 0.3% and 0.7%, respectively for K^{+} and 1.0% and 1.3%, respectively for Ca^{2+}. Changes in pH, K^{+} and Ca^{2+} were measured due to their

association with fatigue during exercise, and Na^+ was measured as a marker of hydration.

2.10.6.1 pH sensor

The pH sensor is based on the principle of ion-selective electrodes. That is, an electrical potential can be established across a membrane that is selectively permeable to a specific ion. The pH sensor is a polyvinyl chloride based ion-selective electrode, consisting of an internal Ag/AgCl reference electrode and an internal salt layer. Their potentials are measured against the card reference electrode. Manufacturer day-to-day and total SD's were 0.005% and 0.007% (SD provided by manufacturer as differences are so small that %CV would be misleading).

2.10.6.2 Calculation of bicarbonate ($HCO3^-$)

Bicarbonate concentrations were derived from pCO_2 and pH values using equation 2.1, which was provided in the manufacturer instructions for the blood gas analyser. Bicarbonate concentrations were measured to assess deviations in buffering capacity during exercise.

$$Equation\ 2.1:\ HCO3^- = 10^{(pH + \log(pCO_2) - 7.608)}$$

2.10.7 Calculation of plasma volume changes

Changes in plasma volume (%) were calculated by the method described in Dill and Costill (1974) using haemoglobin (Hb) and haematocrit (Hct) values.

2.10.7.1 Haemoglobin (Hb)

In all studies Hb was measured using capillary (chapters 5b, 6a and 6b) or venous (chapter 5a) whole blood using a point-of-care system (Hemocue 201+; Hemocue AB, Ängelholm, Sweden). Manufacturer derived within-run and total precision is 0.5% and 0.7%, respectively.

2.10.7.2 Haematocrit (Hct)

In chapters 5a and 5b, Hct was calculated from Hb concentrations using the standard threefold conversion (Hct = Hb*3). In chapters 6a and 6b Hct was determined using the GEM Premier 3000 analyser which measured the

electrical conductivity of 170 µl of whole blood (σblood) and relating it to the Hct (in %) and the plasma conductivity (σplasma) using Equation 2.2 (from manufacturer instructions). A CV of 5.0% represented the precision of measurement.

Equation 2.2: $\sigma blood/\sigma plasma = (1 - Hct/100)/(1 + Hct/100)$

2.11 HYDRATION ANALYSES

Urine (chapters 5a to 6b) and plasma (chapters 5a, 6a and 6b) osmolality was analysed using freezing point depression of 20 µl of plasma or urine (Advanced Model 3300 Micro-Osmoeter; Advanced Instruments Inc., Norwood, MA, USA). The osmometer was calibrated when required using solutions of known osmolality. The interassay CV is 1.5%.

2.12 STATISTICAL ANALYSES

Specific statistical analyses conducted for each study are provided in the relevant chapter.

3.0

PRACTITIONERS' PERCEPTIONS OF THE SOCCER EXTRA-TIME PERIOD

This work has been published in a peer reviewed journal:

Harper LD, Fothergill, M, West DJ, Stevenson E, Russell M. Practitioners' perceptions of the soccer extra-time period: implications for future research. PLoS ONE 11(7): e0157687

This work also won second place in the Young Investigator Award at the International Science and Football Association annual conference in Doha, Qatar, March 2016.

Chapter Summary

- Qualitative research investigating soccer practitioners' perceptions can allow researchers to create practical research investigations.
- Using an open-ended online questionnaire containing eleven main and nine sub questions, the perceptions of extra-time from 46 soccer practitioners, all working for different professional soccer clubs was gathered. Questions were related to current practices, views on extra-time regulations, and ideas for future research.
- A similar number of practitioners account (50%) and do not (50%) account for the potential of extra-time when training and preparing players and 89% of practitioners stated that extra-time influences recovery practices following matches.
- 91% of practitioners believe more research should be conducted on ET. In order of importance, practitioners see the following as future research areas: nutritional interventions, fatigue responses, acute injury risk, recovery modalities, training paradigms, injury epidemiology, and environmental considerations.
- This study presents novel insight into the practitioner perceptions of extra-time and provides information to readers about current applied practices and potential future research opportunities.

3.1 INTRODUCTION

Soccer is an intermittent team sport, requiring periods of both low- and high-intensity activity, and skill execution. Soccer matches are typically played as two 45 min halves, however; an additional 30 min is required (termed extra-time; ET) when a match requires an outright winner and scores are level after 90 min. Between 1986 and 2014, 35% of senior FIFA World Cup matches have required ET, including the last three finals. The requirement for ET in soccer tournaments is becoming more prevalent, with 50% of knockout matches at the 2014 FIFA World Cup requiring 120 min of match-play when compared to 25% at the 2002 and 2010 FIFA World Cup's, and 38% at the 2006 competition.

Research into the responses to ET is in its infancy despite the volume of literature examining the demands of soccer match-play (Mohr et al., 2005; Stolen et al., 2005; Bangsbo et al., 2007). Recently, authors have indicated that ET has a negative impact on both technical (chapter 4) and physical (Russell et al., 2015) performances. For example, in chapter 4, there were reductions in the total number of passes and the number of successful passes and dribbles during ET relative to 90 min. Moreover, during an English Premier League reserve team cup match, with data derived from 10 Hz GPS units, Russell et al., (2015b) observed reductions in total distance covered, high intensity distance covered, number of sprints and the total number of accelerations and decelerations. As these are important aspects of successful soccer performance (Bradley et al., 2014), it appears that ET has negative implications for players.

Contemporary qualitative research involving professional soccer practitioners has investigated the use of training load and player monitoring Akenhead et al., (2015), warm-up practices (Towlson et al., 2013), and injury prevention strategies (McCall et al., 2014; McCall et al., 2015). Developing a deeper understanding of how applied practitioners operate in a professional environment can allow researchers to better appreciate the complexities involved, and conduct research that is both pertinent and effective. Drust & Green (2013) suggest a theoretical model which is similar to that of Bishop (2008) implying that researchers should investigate the aetiology of the problem, conduct descriptive research and gain an understanding into the possible barriers preventing uptake, while undergoing studies to test the

effectiveness of an intervention and its possible implementation in an applied setting.

Consequently, it is important to understand the perceptions and consequences of ET for applied practitioners, and the factors that hinder applied practice and intervention application. This can then be subsequently followed by studies investigating the efficacy of a particular intervention and its transferability to the applied setting. Therefore the aim of this study was to assess practitioner perceptions of ET through qualitative measures (i.e., the use of an open ended online questionnaire). This was to gather information on their opinions of ET, their current practice, and possible future research areas thereby providing scientific researchers with more detailed information regarding the consequences of ET for future research.

3.2 METHODS

Following ethical approval from the Health and Life Sciences Ethics Committee at Northumbria University, 120 practitioners from national and international soccer teams were identified as having roles associated with the preparation and recovery practices of elite soccer players. Practitioners were contacted either electronically (email or social media, *n* = 55) or *via* postal letter (specifically addressed to a member of sport science team as found on club website, *n* = 65) between July and September 2015. Only one practitioner per soccer team was contacted. Only one response per team was requested to ensure the findings were not influenced by multiple responses from the same team. It was emphasised at point of contact that the practitioner must have a role associated with the preparation and recovery practices of elite soccer players. Completed responses were returned by staff from 46 individual teams, representing a 38% response rate; a rate which is higher or similar to previous qualitative research involving soccer practitioners (Towlson et al., 2013; McCall et al., 2014; McCall et al., 2015; Akenhead et al., 2016).

Participant information was provided before the survey and each practitioner gave consent before study involvement. The survey was created using an online resource (Bristol Online Surveys, University of Bristol, UK) with an approximate completion time of 10 min. All responses were anonymous, with practitioners not being required to disclose their name or affiliation, but only their role, competitive level, and general location (Tables 3.1 and 3.2). The survey contained eleven main questions with nine sub questions in a scaled, rank or open ended format (see Appendix 5). The unstructured or open ended component allowed practitioners to expand upon and provide further detail with regards to their own ET practice and experiences. The desired elaboration of specific points was encouraged by activating a feature that required a conscious button click to progress to the next question.

Table 3.1 Practitioner role within their professional soccer team

Role	*n*
Sport Scientist	21
Fitness Coach	9
Strength and Conditioning Coach	4
Sport Performance Manager	4
Physiotherapist	3
Athletic Trainer	2
Team Doctor	1
Exercise Physiologist	1
Head of Science and Medicine	1

Table 3.2 League and competitive level of practitioners

League and Level	*n*
English Premier League Academy	6
English Premier League Senior	5
English Championship Senior (second tier)	4
English League One Senior (third tier)	4
English League Two Senior (fourth tier)	4
Major League Soccer	4
Italian Serie A Senior	3
International Team Senior (country unspecified)	3
Academy Level (location unspecified)	3
French Ligue 1 Senior	2
Elite Level (location unspecified)	2
International A Squad	1
Liga MX (Mexico) Senior	1
Australian A-League Senior	1
Eredivisie Senior (Netherlands)	1
English League One Academy	1
Danish Superliga Academy Team	1

3.2.1 Survey Topics

3.2.1.1 ET and match success

Practitioners stated how much they agreed with the following question: '*extra-time is an important period for determining success in football match play*' by

using a 5-point Likert-type scale with the following options given: *strongly agree, agree, neither agree or disagree, disagree, strongly disagree*.

3.2.1.2 Current ET regulations

Practitioners views regarding the use of a fourth substitution during ET (as per FIFA discussions at International Football Association Board meetings held in February 2015; www.fifa.com) were ascertained by their yes or no responses to the question 'FIFA are currently considering allowing a fourth substitution during extra-time. Do you believe this is warranted?'

3.2.1.3 Nutritional interventions and ET

Practitioners' perceptions of the effectiveness of hydro-nutritional ET interventions were assessed by level of perceived importance using a 5-point Likert-type scale (*very important, important, somewhat important, not important, not sure*). The current use of any particular nutritional supplementation strategy before or during ET was assessed with opportunity for practitioners to elaborate on the specifics of the intervention or to provide further details about why no particular hydro-nutritional interventions were employed. The perceived importance of the use of nutritional products prior to ET relative to other time points (i.e., pre-match or half-time) was also assessed.

3.2.1.4 Research paradigms

To determine if the practitioners felt that more research should be conducted into ET, the level of importance (*very important, important, somewhat important, not important, not sure*) of the following research areas was investigated: *fatigue responses*, *nutritional interventions*, *training paradigms*, *recovery modalities*, *environmental considerations*, *injury epidemiology*, and *acute injury risk*. Practitioners were also given the opportunity to suggest other areas or factors they felt were important which had not been mentioned directly whilst those who selected *not important* were able to give their reasons why.

3.2.1.5 Current Preparation and Training Practices

Practitioners specified what they did differently or adapted if an upcoming match had the potential to go to ET when training and preparing their players, or to give reasons for not making any adjustments.

3.2.1.6 Current Match-Day Practices

To examine the influence of the potential for ET on match-day practices when compared to matches of only 90 min duration, practitioners were asked to specify any modifications to practice or provide reasoning as to why usual procedures remained unchanged. In order of importance, respondents ranked what they advocated to players during the five min break separating the cessation of normal time and the beginning of ET from the following options: *energy provision*, *hydration*, *massage*, *tactical preparations*, or *other* (which they were asked to specify). Practitioners also stated the applicability of these strategies in the two minute break between the 15 min halves of ET, stating which were the most important or why they were not applicable.

3.2.1.7 Current Post-Match Practices

To investigate the influence of ET on recovery modalities and training prescription, the practices performed in the immediate (e.g., same day) and prolonged (e.g., +24 and +48 hour) periods following a match requiring ET was explored. Practitioners were provided with an opportunity to state what changes were made, if any, or to elaborate on the decision to not modify practices following ET involvement. Practitioners also proposed a list of recommendations that they would make to recovery strategies if given the opportunity.

3.2.2 Data Analysis

The study design is of a cross-sectional and descriptive nature and as such, the data is presented in a descriptive manner. For questions with categorical responses, points for the level of importance were awarded as thus: '*very important*' – 3 points, '*important*' – 2 points, '*somewhat important*' – 1 point, '*not sure*' – 0.5 points, '*not important*' – 0 points, as per McCall et al., (2015). Thereafter, total accumulated points were calculated and answers ranked in order of highest to lowest. For questions utilising a Likert-scale, frequency analysis was used to establish the percentage of practitioners who had endorsed a particular response. For the question regarding what practitioners advocated prior to ET (i.e., question 8a, Appendix 5) the option rated first was

awarded 5 points, second - 4 points, third - 3 points, fourth - 2 points, and fifth - 1 point. Points were then collated to determine mean order of importance.

Written responses for the open-ended questions were read several times for familiarisation and to develop a full understanding of the content (Thomas, 2006). The raw data were then organised and subjected to inductive content analysis by the lead author. Inductive analysis is a data driven technique which occurs independently of any pre-existing frameworks or preconceptions (Patton, 2015). Similar emergent themes were classified as general dimensions and assigned a descriptive overarching label. Second order themes were then established and inductive analysis continued until data saturation had occurred. In view of the lead author's prior knowledge of the research area, the research team employed independent validation of the themes at every stage of analysis. Moreover, peer debriefing and member checking (a form of independent validation) was also employed by the research team to enhance credibility and ensure that an accurate representation of the data had occurred (Creswell & Miller, 2000). In the final stages of analysis a deductive approach was employed to confirm the validity of the inductive analysis and to establish any theoretical relationships within the data (Patton, 2015).

3.3 RESULTS

From the inductive and deductive analysis, seven general dimensions emerged from the data with regards to practitioners' views on ET, and their current or ideal ET preparation. These were 'importance of ET', 'rule changes', 'efficacy of ET hydro-nutritional provision', 'nutritional timing' 'future research directions', 'preparatory modulations', and 'recovery'.

3.3.1 Importance of ET

The majority of practitioners (63%, *n* = 29) either agreed or strongly agreed that *extra-time is an important period for determining success in football match play* whereas 30% (*n* = 14) neither agreed nor disagreed, with the remaining 7% of respondents (*n* = 3) disagreeing with this statement.

3.3.2 Rule changes

Notably, 67% (*n* = 31) of practitioners felt that a fourth substitution should be allowed in ET; however, 33% (*n* = 15) felt that current substitution rules (i.e., three substitutes throughout whole match duration) should remain. Three second order themes were identified for practitioners in favour of a fourth substitute: fatigue (e.g., *'it will help to improve performance and reduce fatigue')*, injury risk (e.g., *'allow for any injuries and to decrease load related injuries in future training and games'*), and tactical modifications (e.g., *'may make for differing team strategies'*).

Conversely, support for current rulings to remain was explained by three second order themes, namely: lack of evidence of risk (e.g., *'I don't think extra time poses a 'risk' to players who have played the full match and so I am unsure what the rationale for a fourth substitute is; if they want to avoid meaningless periods of play due to fatigue, reintroduce the golden goal concept'*), players are fit enough *(*e.g., *'players are able to complete 120 minutes'*), and preparedness (e.g., *'the better conditioned teams should be rewarded for their hard/smart work'*).

3.3.3 Efficacy of ET hydro-nutritional provision

Practitioners were asked about the effectiveness of hydro-nutritional ET interventions; with none stating hydro-nutritional ET interventions were not important. The majority (89%, *n* = 41) believed that they are either very important or important and 11% (*n* = 5) found them somewhat important.

3.3.4 Nutritional Timing

When asked whether the use of nutritional products prior to ET was more important than at any other time point, 59% (*n* = 27) of practitioners disagreed whereas 41% (*n* = 19) agreed. The following second order themes were identified as reason for it not being the most important time point: similar importance (e.g., *'I think it is equally as important as both prior to kick off and at a half time. The players must be fully nourished the whole time'*), lack of benefit/evidence (e.g., *'timeframe probably too short to have any real physical impact – probably more psychological*), and other time points are more important (e.g., *'no, I believe the food consumption 24-48 hours prior to match-play has the greatest impact on performance'*).

Fatigue (e.g., *players are in a state of fatigue prior to extra time and physiologically and psychologically require an energy boost*), and diminished energy supply prior to ET (e.g., *'glycogen depletion might influence performance more after 90 min of play'*) were identified as second order themes regarding why the break before ET is the most important time point for ingestion of nutritional products.

3.3.5 Future research directions

Respondents were mostly positive towards the need for further research into ET (i.e., 91%, *n* = 42) with only 9% (*n* = 4) of practitioners disagreeing with this statement. Second order themes were identified for disagreement as: scarcity (e.g., *'happens too infrequently – other bigger issues more important'*), and no issues (e.g., *'I don't perceive extra time as an issue for players well prepared'*). The accumulated points of importance for potential research areas are given in Figure 3.1, with nutritional intervention studies viewed as the most important, followed by, in order of importance, research into fatigue responses, acute injury risk, recovery modalities, training paradigms, injury epidemiology, and lastly, environmental considerations. Six respondents gave other areas that

were not mentioned but which they felt were important. When these areas were grouped into second order themes, psychological (e.g., *'does the team with momentum at the end of 90 minutes continue into the extra time period'*), and performance outputs (e.g., *'alterations in physical markers during this period, for example, m/min'*) emerged.

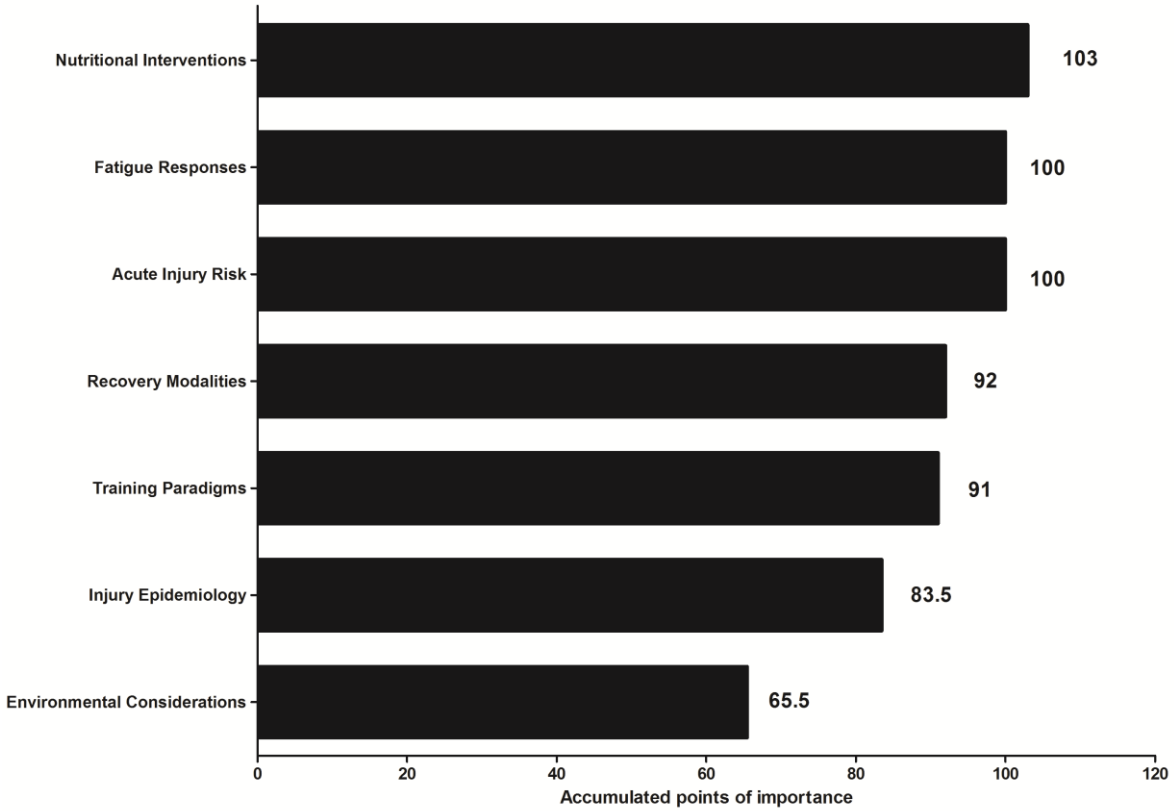

Figure 3.1 Accumulated points of importance for future extra-time research areas

3.3.6 Preparatory Modulations

A similar number of practitioners account (50%, *n* = 23) and do not (50%, *n* = 23) account for the potential of ET when training and preparing their players. The second order themes that I identified relating to the changes made to preparations are provided in Table 3.3.

Table 3.3 Second order themes (***bold italicised***) with quotes to support why or why not changes are made to pre-match preparations.

Changes that are made pre-match
Training modulations*: 'adapt training in build up to a fixture that may go into extra time'; 'reduce training intensity/duration 2 days prior to match'; 'taper, with reduction in volume 2-3 days pre-match'; 'additional fitness or small-sided games added on to end of training'*
Nutritional adjustments*: 'additional food strategy used (supplements)'*
Player education*: 'before games with the potential of extra-time, players are informed of the importance of hydration and calorie intake'*; *'ensure players follow a structured post training recovery and nutrition strategy prior to the game'*
Why changes are not made pre-match
Injury risk: '*incorporating training with a view to maximizing performance in the extra time period year round (as a fixture requiring extra time could occur at any stage of the season depending on success) would result in higher loads and increased injury risk'*
Scarcity: *'too infrequent'; 'does not occur frequently enough to be considered as a pertinent training variable to address'; 'it is not a frequent enough occurrence to warrant increased workload throughout the season'*
Insufficient time to improve fitness: *'playing every 3 days limits ability to develop fitness – players rotation and management is key'; 'unlikely a single microcycle would be enough to induce required adaptations'*
Priorities: *'focus on league games – may not even be involved in any extra time in a whole season'; 'majority of games we play are 90 minutes and we base training loads around 90 minute games'*
Unnecessary: *'players are overloaded so specific training and preparation is not needed'; 'a fit group should be capable to cope with around 1 or 2 matches per season'*

When asked if they revised or adapted their current match-day practice in light of the potential of ET, 67% (*n* = 31) of practitioners reported no changes were made whilst 33% (*n* = 15) stated that changes were made. Six second order themes emerged regarding practitioners' match day practices. Hydro-nutritional adjustments (e.g., *provide more fuel sources, i.e., carb/caffeine gels')* and player management (e.g., *'consider squad rotations more closely'*) were two second order themes related to changes that practitioners make to their preparatory practices. Infrequency (e.g., *'only small chance of extra time'*), normal time being of greater importance (e.g., *'we prepare to win the game in regulation as we would any game'*), preparedness (e.g., *'we prepare for the game as per normal, players should be optimally fuelled and hydrated in preparation for any game*), and negative impact of change (e.g., *'we treat each match with the same preparation as to not upset the normal pre-match routine of our squad'*) were recognised as four second order themes for not modifying current preparatory practices.

Figure 3.2 shows the accumulated points of importance of what practitioners typically advocated to their players in the five minute break between the end of 90 min and the beginning of ET. Hydration was identified as the most important, followed by energy provision, massage, tactical preparations and other practices. Other practices advocated to players are listed on Figure 3.2. Furthermore, 85% (*n* = 39) of practitioners felt that the two min break between the two halves of ET was an opportunity to apply the strategies stated above, with hydration (54%), energy provision (37%) and tactical preparations (10%) seen as the most applicable at this time point (Figure 3.3). Additionally, 87% (*n* = 40) of practitioners advocate a particular nutritional supplementation strategy prior to ET. I identified two second order themes: *hydration* (e.g., *'electrolytes'*; *'water'*), *energy provision* (e.g., *'high CHO drinks or gels'*; '*high glycemic index snack –jelly beans'*; *'caffeine'*; *'protein'*). Second order themes identified from the 13% (*n* = 6) who do not recommend anything in particular prior to ET were: efficacy (e.g., *'not enough time to take effect'*), and habitual (*'continue using the same players train with and have used already in the game'*).

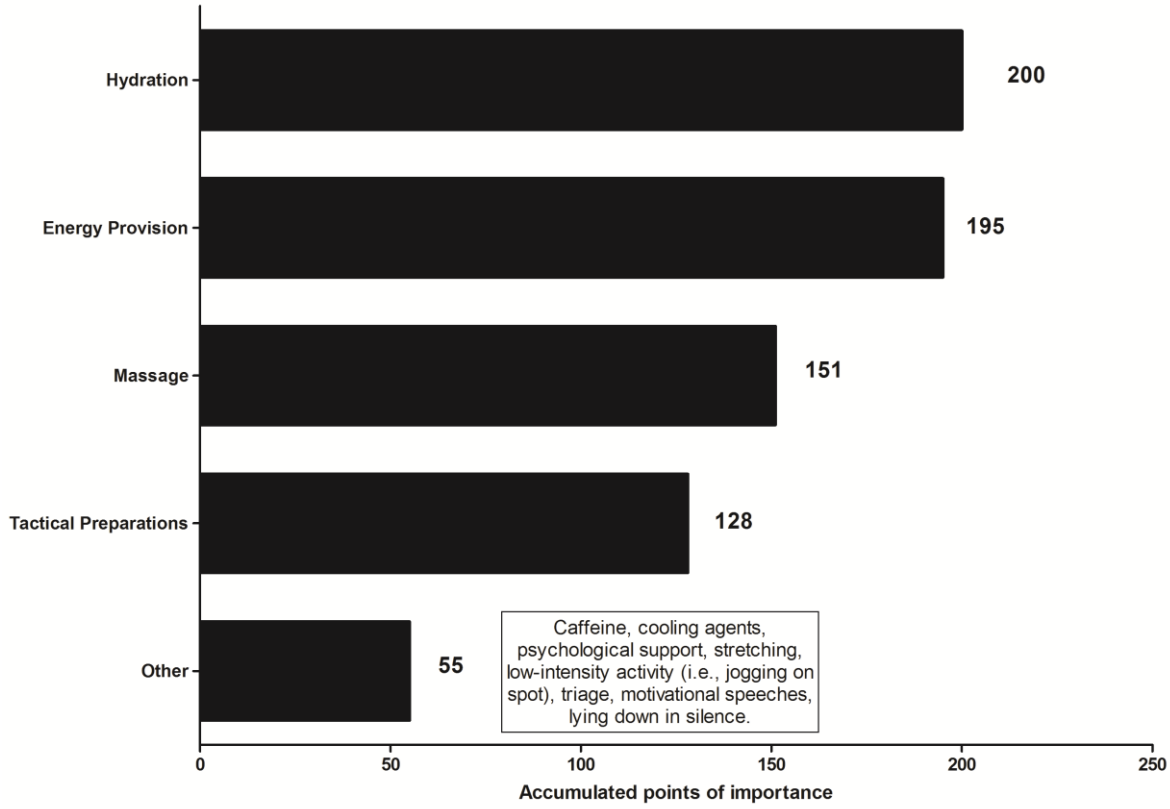

Figure 3.2 Accumulated points of importance for what practitioners advocate to players in the five min break prior to extra-time

3.3.7 Recovery

Notably, 89% (*n* = 41) of practitioners stated that ET influences the recovery practices in the immediate and prolonged periods following a match, with 11% (*n* = 5) stating that no changes are made. Only one second order theme for not changing recovery was identified: current system (e.g., *'post-match recovery strategies are implemented following the same method as league matches'*). The changes that practitioners make are given in Table 3.4, along with a list of changes related to recovery that they would make if given the choice.

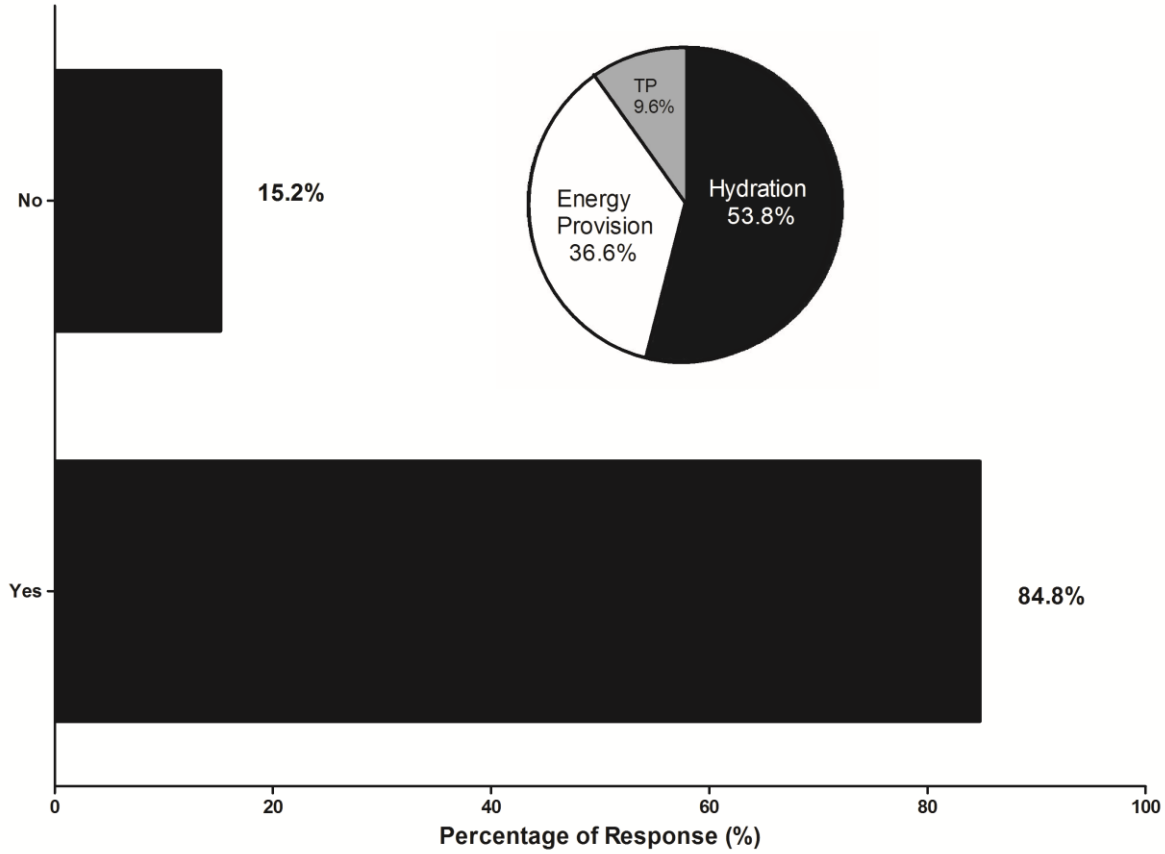

Figure 3.3 Percentage of practitioners who do or do not advocate a particular strategy in the break between the two halves of extra-time. Pie chart depicts what practitioners advocate by percentage. TP = tactical preparations.

Table 3.4 Second order themes (***bold italicised***) with quotes to support why or why not changes are made to recovery following matches requiring extra-time.

Changes to recovery practices following matches that require extra-time
Training modulations: *'training adapted to wellness scores, countermovement jump performance, ankle mobility, hip internal rotation range of motion, hamstring mobility, and adductor strength scores'; 'split squad into 2nd/3rd days with reduced intensity'; 'late start to training match day +1 for extra sleep'*
Recovery modifications: *'all recovery modalities become compulsory'; 'mandatory ice baths, foam rolling and massage'; 'additional time spent promoting flexibility/mobility work for 72 hours post-match'*
Nutritional adjustments: *'increased carbohydrate and protein provision'; 'increased carbohydrate consumption 0-48 hrs post match'*
Changes to recovery strategies if given the choice
Training modulations*: 'additional passive rest days to allow players to be unloaded'; 'reductions in training load 48hrs post match'*
Nutritional adjustments: *'increased intake of recovery promoting foods'; 'cooked meal in the dressing room'; 'increased carbohydrate provision'*
Recovery modalities: *'pool based recovery – post game + following day'; 'access to hydrotherapy immediately following match'; 'mandatory ice baths'*
Monitoring tools: *'increased fatigue monitoring of individuals'; 'extra markers such as blood, saliva and sleep would be interesting to monitor more closely'*

3.4 DISCUSSION

The aim of this study was to assess the perceptions of professional soccer practitioners concerning the ET period. This included understanding current and ideal practices and opinions on ET, as well as elucidating future research areas. This is the first study to investigate perceptions of ET in this population and as such provides novel findings in the emerging area of ET research.

The majority of practitioners (63%) felt that ET is an important period for determining success in a soccer match and as such they feel they may be able to influence match outcome. A high number of domestic and international cup competitions stipulate in the rules of competition that a 30 min ET period must be played if matches are tied at 90 min (www.fifa.com; www.uefa.com). Between 1986 and 2014, 35% of senior FIFA World Cup knockout matches have required ET, including the last three finals. In the annually held English League Cup (LC) competition, 23% of matches required ET from August 2011 to February 2015. Notably, 39% (n = 18) of our sample are practitioners working for teams involved in this competition. All LC matches (except the final) are played midweek, with league matches played on the preceding and succeeding Saturday or Sunday. Furthermore, knockout matches played in major international tournaments such as the FIFA World Cup or UEFA European Championships are typically separated by 72 h. If matches are of normal duration (i.e., 90 min), this may still have implications for recovery as congested fixture periods have been shown to increase injury risk (Bengtsson et al., 2013), and physiological stress (Mohr et al., 2016) and diminish some aspects of tactical (Folgado et al., 2015), and physical performance (Arruda et al., 2015). Notably, 89% of the practitioners sampled in this study changed their recovery strategies following a match requiring ET, with second order themes identifying: training modulations, recovery modifications and nutritional adjustments (Table 3.4).

No research currently exists investigating the influence of a match requiring ET on recovery and subsequent performance in matches of close temporal proximity. As indices of technical and physical performance have been shown to reduce in ET (chapter 4, Russell et al., 2015b), it would seem logical that recovery may also be compromised, however; this supposition remains to be

investigated. A number of recovery strategies that practitioners would like to utilise in their applied setting are also given in Table 3.4 and include monitoring tools and recovery modalities. Notably, recovery modalities are considered the fourth most important future research area (Figure 3.1). A number of recovery strategies purported to accelerate recovery and improve soccer performance have been examined (for a review see Nedelec et al., 2013). However, the effectiveness of these strategies for recovery from a match requiring ET has yet to be investigated.

Practitioners were predominately positive about the use of nutritional interventions prior to ET and future research on their effectiveness. Indeed, 89% of practitioners felt that hydro-nutritional interventions in the five min break between 90 min and ET were very important or important, with the remaining 11% finding them somewhat important. A large majority (87%) of practitioners recommend a particular nutritional supplementation strategy to their players prior to ET. Recommendations include hydration and energy provision. However, evidence supporting the use and efficacy of nutritional interventions during ET are lacking. Furthermore, imbibing carbohydrate-electrolyte solutions during exercise has also been shown to elongate time to fatigue during intermittent shuttle running following a 90 min soccer-specific simulation (Foskett et al., 2008). The acute benefits of carbohydrate supplementation on skill performance (Russell et al., 2014), intermittent exercise performance (Baker et al, 2015) and prolonged periods of exercise (Stellingwerff et al., 2014) are well known. Further investigations are required to optimise hydro-nutritional strategies for players engaging in ET, especially as the practitioners I sampled believe nutritional intervention studies are the most important area for future research (Figure 3.1).

The use of caffeine as an ergogenic aid is popular (Doherty et al., 2004), however; there are equivocal results regarding its effectiveness during simulated (Gant et al., 2010; Kingsley et al., 2014; Ali et al., 2015a; Ali et al, 2015b) and actual soccer match-play (Pettersen et al., 2014). Some practitioners recommend caffeine prior to ET, however; the effectiveness of such a strategy is yet to be researched. Peak serum caffeine concentrations are typically observed 30-45 min post-ingestion; therefore the full ergogenic benefit of ingesting caffeine prior to ET may not be achieved. However, caffeinated

gum, which stimulates caffeine absorption quicker than capsule form (Kamimori et al., 2002) may provide a more efficient method of ingestion. Nonetheless, caffeine ingestion prior to ET may possibly compromise post-match sleep quality (Ali et al., 2015b) especially as ET periods are predominately played at night, with some matches finishing as late as 23:30 h.

The majority of practitioners felt that the two min break between the two halves of ET was an opportunity to implement strategies to improve performance (see Figure 3.3). However, the two min break is typically seen as the only opportunity for teams to switch halves, without returning to the technical area, therefore making it difficult to implement any particular strategy. From anecdotal observations, the actual length of time for the break tends to vary. Indeed, during the FIFA World Cup in Brazil in 2014 the players were given an extended break lasting ~5 min. Practitioners should be cognisant of the fact that it may not be possible to always gain access to the players during this break, as it would seem to be under the referee's discretion. As hydration and energy provision are seen as the main strategies used, practitioners should place hydro-nutritional products in the goalmouth or close to pitch-side for the players to readily use.

Half of practitioners modified pre-match practices to account for the potential of ET. Currently, no data exists that has examined the influence of training modalities on performance during ET. Implementing specific training microcycles to try and acutely enhance adaptations may be difficult, with barriers including injury risk and insufficient time to improve fitness (Table 3.3). Although in-season twice weekly high-intensity interval training has been shown to improve maximal aerobic speed and 40 m sprint velocities (Dupont et al., 2004), this training was performed over a 10 week period. The acute benefits are unlikely to be obtained if the training is performed only in the week leading up to the match. Changes that practitioners make related to training are varied, with some reducing volume and some providing an extra exercise stimulus (training modulations; Table 3.3).

Practitioners make changes to diet (nutritional adjustments; Table 3.3) and emphasise good nutritional habits (player education; Table 3.3) in the days prior to a match that may require ET. Adequate energy intake relative to match

demands is considered important (Briggs et al., 2015), with insufficiencies potentially leading to negative effects on performance (Souglis et al., 2013). Therefore, as it is likely players will expend more energy during ET than during 90 min; energy intake in the days prior to the match must be optimised. The majority (67%) of practitioners did not change any of their usual match-day practices on a match-day that may involve ET. Currently, little evidence exists regarding the influence of ET on performance or the aetiology of fatigue. As 91% of practitioners feel that future research should be conducted on ET, with fatigue responses as the second most important area (Figure 3.1), researchers should consider avenues to further investigate this period of play.

The influence of ET on acute injury risk has yet to be investigated, with practitioners considering it the joint second most important research area (Figure 3.1). Epidemiological and quantitative data suggest that there is a greater risk of muscular injury during the last 15 min of a 90 min match, with comprised lower body strength output and movement mechanics postulated as potential mechanisms (Greig et al., 2008; Cohen et al., 2015; Jones et al., 2015). Furthermore, a passive half-time period has been demonstrated to increase hamstring injury risk (Small et al., 2009). Future research is required to assess acute injury risk during ET as well as following the passive 5 min break that precedes ET. Furthermore, epidemiological studies, similar to the UEFA Champions League study (Bengtsson et al., 2013), are required to both assess the incidence and type of injury sustained in ET, and the influence of ET on injury incidence during periods of fixture congestion.

A rule change to allow a fourth substitute in ET has been proposed on a number of occasions by FIFA. Indeed, in March 2016 the International Football Association Board advisory panel sanctioned the trialling of a fourth substitute at the 2016 Olympic games in Rio de Janeiro, the FIFA Under-20 Women's World Cup 2016 in Papua New Guinea and the FIFA Club World Cup 2016 in Japan. The majority of practitioners (67%) were in favour of the introduction of a fourth substitute, with fatigue, injury risk and tactical modifications identified as second order themes. Further research is required to ascertain the influence of an additional substitute on player health, performance, and match outcome.

Environmental considerations were considered the least important of the seven suggested future research areas (Figure 3.1). This may be due to the location of the practitioners sampled (i.e., predominately from temperate climates close to sea level). However, the negative influence of the environment (i.e., temperature and altitude) on soccer performance has been demonstrated previously (Levine et al., 2008; Mohr et al., 2012). With FIFA World Cup tournaments (i.e., Qatar 2022, Brazil 2014, South Africa 2010), and other major matches (Champions League final 2014, Berlin, Germany; 26°C, and UEFA European Championship final 2012, Kiev, Ukraine; 26°C) potentially played at altitude or in the heat, the health risks and performance effects of such conditions during ET require investigation.

Although other approaches have been used for qualitative data analysis (e.g., grounded theory; and narrative analysis), the general inductive approach used presently has been demonstrated as a simple, robust method to analyse qualitative data (Thomas, 2006). It is prudent to note when invited to partake in the investigation, practitioners were made aware of the topic (i.e., ET). It is therefore acknowledged that the respondents who did not complete the questionnaire may not have had an interest in ET, possibly skewing our findings. Furthermore, practitioners completed the questionnaire during the months of July, August, and September and as such, their team may not have yet been exposed to ET in that competitive season. However, it is likely they had been exposed to ET in previous seasons; therefore their present circumstances were unlikely to influence their responses.

3.5 CONCLUSIONS

In summary, this study presents a novel insight into practitioner perceptions of the soccer ET period. Evidence has been provided demonstrating that the majority of practitioners feel that ET is an important period of match-play for success and endorse the use of a fourth substitution in ET. Furthermore, information regarding what research practitioners consider should be conducted in future, and how they currently prepare and recover players participating in ET has been provided. Not only could coaches and practitioners use this information to inform current practices, researchers could use this information to develop innovative research projects to both better understand the influence of ET on performance, but also intervention strategies that could be tested and then applied to the target population (i.e., professional soccer players).

4.0

TECHNICAL PERFORMANCE REDUCES DURING THE EXTRA-TIME PERIOD OF PROFESSIONAL SOCCER MATCH-PLAY

This work has been published in a peer reviewed journal:

Harper LD, West DJ, Stevenson E, Russell M. Practitioners' perceptions of the soccer extra-time period: implications for future research. PLoS ONE 9(10): e110995

Chapter Summary

- Despite the importance of extra-time in determining progression in specific soccer tournament matches, few studies have profiled the demands of 120-minutes of soccer match-play.
- The practitioners surveyed in chapter 3 identified 'fatigue responses' as the third most important future research area.
- Using video footage from 18 professional matches that required ET (i.e., had a duration of 120 min), a notational analysis technique was used to investigate transient changes in technical (i.e., skill performance) throughout each match.
- The number of successful passes, total passes, and successful dribbles were reduced in the last 15 min of ET compared to previous 15 min periods.
- These results demonstrate that match-specific factors reduced particular indices of technical performance in the second half of ET.

4.1 INTRODUCTION

Soccer is a high-intensity intermittent sport which is normally played over 90 min. However, when scores are tied at the end of certain matches in soccer tournaments (e.g., FIFA World Cup, UEFA Champions League, FA Cup etc.), an extra-time period, consisting of two additional 15-min periods of play, follows the end of normal time. Notably, between 1986 and 2010, 33 matches have required that extra-time be played in FIFA World Cup competitions. In the 2014 FIFA World Cup, of the matches played in the knockout stages, 50% required extra-time to be played. Although the physiological and performance responses to the normal duration (i.e., 90 min) of soccer match-play have been extensively researched (Mohr et al., 2003; Rahnama et al., 2003; Di Salvo et al., 2007; Rampinini et al., 2009; Russell et al., 2011a), comparable data during the extra-time period is lacking. This is somewhat surprising considering the role that this additional period of play has in determining success in tournament situations.

The ability to maintain skill proficiency during soccer match-play is considered an important factor in overall player performance and match success (Lago-Penas et al., 2010). However, soccer-specific exercise appears to influence skilled performances executed during normal durations (i.e., 90 min) of match-play. For example, using a within-subject study design, Russell et al., (2013) observed reductions in total possessions and the number of ball distributions in the second versus the first half of English Championship matches. Further analysis across 15-min intervals revealed that the total number of ball possessions and distributions reduced in the final 15 min when compared with the opening phase of play. Although self-pacing strategies (Edwards & Noakes, 2009) and tactical modifications (Weston et al., 2011) have been suggested to explain such changes, these data support studies where the accumulated effects of match-related fatigue have been proposed to explain decrements in short passing performance during Italian Serie A matches (Rampinini et al., 2009) and the increased number of goals conceded in the final 15 min of match-play (Reilly, 2003).

Interestingly, the decrement in skill performance observed throughout soccer-specific exercise appears to differ according to the skill being performed. For example, Rampinini et al. (2009) identified that three quarters of the technical measures examined were similar between halves in Serie A players who experienced physical fatigue decrements. Russell et al. (2013) also identified no changes in five of the seven indices of technical performance (i.e., number of touches taken per possession, number of challenges, percentage of challenges won, length of forward distributions and percentage success of distributions) examined throughout match-play. Therefore, it appears that the technical response to the normal duration of soccer match-play is not uniform. However, it is plausible that the prolonged duration of games that enters in to the extra-time period elicit different technical responses compared to those observed during 90 min. No data is currently available that has profiled the skill response associated with soccer matches where the extra-time period has been played.

Therefore, using performance analysis techniques, the aim of this study was to examine the influence of prolonged durations of actual soccer match-play (i.e., those matches which required extra-time to be played) on markers of technical performance. It was hypothesised that extra-time would influence technical performance.

4.2 METHODS

4.2.1 Participants

Eighteen matches that required an extra-time period to be played were included in the analyses. Only outfield players that completed the full 120 min of the match (i.e., 90 min plus 30 min extra-time) were analysed. Using a within-match approach, the technical actions elicited during matches involving professional European clubs (ranging from the third tier of their domestic league to top tier and International teams) were analysed (15 ± 1 players per match). Written informed consent was obtained from the professional soccer clubs who supplied footage to be analysed for the purpose of the study. The study was approved by the Faculty of Health and Life Sciences Ethics Committee of Northumbria University in Newcastle upon Tyne, UK.

4.2.2 Match Analysis Procedures

In agreement with the experimental design used by previous authors (Russell et al., 2013), skill-related performances were analysed retrospectively during competitive matches played since 2010 using existing footage obtained from television recordings (eight matches) and footage supplied following correspondence with specific clubs (10 matches). To minimise variation, each match was manually coded (Sportstec Gamebreaker, Sportstec™, New South Wales, Australia) by one experienced performance analyst according to operational definitions detailed by Rampinini et al. (2009) and Opta Sports Data (http://www.optasports.com/news-area/blog-optas-event-definitions.aspx). A total of 17 technical variables (Table 4.1) were analysed for each match.

In order to investigate the transient effects of 120 min of soccer match-play on technical performance, all matches were divided into eight 15 min epochs (i.e., E1: 00:00-14:59 min, E2: 15:00–29:59 min, E3: 30:00–44:59 min, E4: 45:00–59:59 min, E5: 60:00–74:59 min, E6: 75:00–89:59 min, E7: 90:00–104:59 min, E8: 105:00–119:59 min). To ensure that the duration of each epoch was standardised, data collected in injury time was not included in the analyses. The intra-observer reliability of measurements was assessed by repeated coding of all measured variables on two occasions for selected epochs in six randomly

chosen matches (Table 4.2). The epochs selected were E1, E6 and E8 as these were considered the most important with regards to any differences between epochs. Reliability testing was conducted in a blinded manner such that the initial values collected were not known until after the retest had been completed. Furthermore, reliability testing was conducted following all analyses to account for any potential learning effect from the first period of analysis.

Table 4.1 Operational definitions of the technical variables analysed (derived from Rampinini et al., (2009) & Opta Sports)

Variable		Operational definition
Passing	Successful passes	A pass that is performed with the foot or head that is received successfully by a teammate
	Unsuccessful passes	A pass that is performed with the foot or head that is not received successfully by a teammate (i.e., is instead either intercepted by an opposition player or leaves the field of play)
	Total passes	Sum of successful and unsuccessful passes
	Pass accuracy (%)	Successful passes divided by total passes, multiplied by 100
Dribbling	Successful dribbles	A situation when a player takes control of the ball and is able to keep possession of the ball before performing another action such as a pass or shot
	Unsuccessful dribbles	A situation when a player takes control of the ball and is subsequently dispossessed by an opposing player or dribbles the ball out of play
	Total dribbles	Sum of successful and unsuccessful dribbles
	Dribble accuracy (%)	Successful dribbles divided by total dribbles, multiplied by 100
Shooting	Shots on target	Any goal attempt that: a) Goes into the net b) Would have gone into the net but for being stopped by a goalkeeper's save c) Would have gone into the net but for being stopped by a defender who is the last man.
	Shots off target	Any goal attempt where the ball is going wide of the target, misses the goal or hits the woodwork
	Total shots	Sum of shots attempted
	Shot accuracy (%)	Shots on target divided by total shots, multiplied by 100
Crossing	Successful crosses	A long pass using the foot that is performed by a player within the last 35 m of the pitch and which is directed into the penalty area and is received by a teammate
	Unsuccessful crosses	A long pass using the foot that is performed by a player within the last 35 m of the pitch and which is directed into the penalty area and is not received by a teammate but is instead controlled or cleared by an opposition player or goes out of play for a goal-kick or throw in
	Total crosses	Sum of successful and unsuccessful crosses
	Cross accuracy (%)	Successful crosses divided by total crosses, multiplied by 100
Time-in-play		The amount of time in seconds per 15 min epoch that the ball is within the field of play. A ball is deemed out of the field of play in the cases of a(n): goal kick, free kick, throw in, penalty, corner, goal celebration, substitution, extraordinary circumstances (e.g., pitch invasions). In these occurrences, the clock is restarted when the ball re-enters the field of play or in the case of goal celebrations, when the subsequent kick-off is taken by the team that conceded the goal.

Table 4.2 Test-retest reliability data (intraclass correlation coefficients) for the technical variables examined

Variable	E1	E6	E8
Successful passes	0.993*	0.999*	0.998*
Unsuccessful passes	0.961*	0.982*	0.997*
Total passes	0.969*	0.998*	0.998*
Pass accuracy (%)	0.982*	0.950*	0.938*
Successful dribbles	0.916*	0.954*	0.999*
Unsuccessful dribbles	0.927*	0.885*	0.827*
Total dribbles	0.892*	0.977*	0.982*
Dribble accuracy (%)	0.929*	0.648	0.715
Shots on target	1.000*	0.615	0.432*
Shots off target	0.851*	0.956*	0.956*
Total Shots	0.937*	1.000*	0.906*
Shot accuracy (%)	0.964*	1.000*	0.135
Successful crosses	0.962*	1.000*	0.968*
Unsuccessful crosses	0.852*	0.982*	1.000*
Total crosses	0.692*	0.977*	0.993*
Cross accuracy (%)	0.946*	0.999*	0.938*
Ball time in play	0.999*	0.968*	0.978*

4.2.3 Statistical Analysis

The appropriateness of statistical methods to analyse data yielded from multiple matches has been debated (Field, 2009; Wilkinson & Akenhead, 2013). To minimise the influence of dependence in the data sets, given that each match has distinct characteristics, a within-match design was used; therefore, the data presented (means ± SD) reflects the cumulative totals of technical actions performed within each match per epoch. Due to violations of normality, differences between time-points were investigated using Friedman's repeated-measures analysis of variance on ranks tests. Where appropriate, post-hoc analyses were applied using Bonferroni-corrected Wilcoxon's signed rank tests. Statistical significance was set at $p \leq 0.05$. Effect sizes (ES) for statistical differences were determined according to Field (2009) with values of 0.2, 0.5, and >0.8 considered to reflect small, medium, and large differences respectively (Cohen, 1988). Test-retest reliability was assessed using intra-class coefficient

(ICC) calculations. All statistical analyses were conducted using SPSS Version 21.0 (IBM, Armonk, NY, USA).

4.3 RESULTS

Extra-time influenced 4 of the 17 technical variables analysed (Table 3). Specifically, the number of successful passes observed during E8 was lower than E1 (-31%, p = 0.001, ES = 0.52), E2 (-22%, p = 0.005, ES = 0.42), E3 (-24%, p = 0.001, ES = 0.50), E4 (-25%, p =0.001, ES = 0.53) and E7 (-17%, p = 0.002, ES = 0.48). Similarly, the total number of passes made in E8 was reduced when compared to E1 (-30%, p = 0.001, ES = 0.52), E3 (-21%, p = 0.002, ES = 0.49), E4 (-21%, p ≤ 0.0005, ES = 0.54) and E7 (-15%, p = 0.001, ES = 0.50). Furthermore, dribbling success in E8 was reduced when compared to E1 (-32%, p = 0.001, ES = 0.50) and E3 (-24%, p ≤ 0.0005, ES = 0.59). The time the ball was in play was less in E8 compared to E1 (-16%, p ≤ 0.0005, ES = 0.55). All other technical variables analysed, including shooting and crossing indices, were similar between extra-time and the rest of the match.

Table 4.3 Technical performance variables (mean ± SD) as a function of timing throughout matches

Variable	Timing throughout match								Time effect		Post-hoc differences ($P \leq 0.006$) compared to E7 and E8
	E1	E2	E3	E4	E5	E6	E7	E8	Chi Square ($X^2_{(7)}$)	*P* value	
Passing											
Successful passes	88 ± 23	77 ± 21	79 ± 18	80 ± 21	66 ± 20	65 ± 17	73 ± 20	61 ± 23	32.91	<0.0005	E8 vs. E1, E2, E3, E4, E7
Unsuccessful passes	14 ± 5	12 ± 5	11 ± 4	13 ± 4	10 ± 3	10 ± 5	11 ± 4	11 ± 5	22.97	0.002	
Total passes	102 ± 22	89 ± 21	91 ± 19	93 ± 22	76 ± 21	76 ± 21	84 ± 20	71 ± 25	37.23	<0.0005	E8 vs. E1, E3, E4, E7
Pass accuracy (%)	85 ± 7	86 ± 7	87 ± 5	86 ± 4	86 ± 6	86 ± 5	87 ± 6	84 ± 7	4.10	0.769	
Dribbling											
Successful dribbles	14 ± 4	13 ± 5	12 ± 4	13 ± 5	11 ± 4	12 ± 4	11 ± 3	9 ± 4	15.79	0.027	E8 vs. E1, E3
Unsuccessful dribbles	5 ± 3	5 ± 2	4 ± 1	4 ± 3	4 ± 2	5 ± 2	4 ± 2	5 ± 2	7.20	0.408	
Total dribbles	18 ± 4	18 ± 6	16 ± 5	17 ± 5	15 ± 4	16 ± 4	15 ± 3	15 ± 5	13.12	0.069	
Dribble accuracy (%)	72 ± 15	74 ± 12	76 ± 9	72 ± 18	72 ± 14	71 ± 16	72 ± 12	64 ± 16	8.17	0.318	
Shooting											
Shots on target	1 ± 1	1 ± 1	1 ± 1	1 ± 1	2 ± 1	1 ± 1	1 ± 1	1 ± 1	11.45	0.120	
Shots off target	2 ± 1	2 ± 1	2 ± 2	2 ± 2	2 ± 1	3 ± 2	2 ± 1	2 ± 1	11.57	0.116	
Total shots	3 ± 2	2 ± 1	3 ± 2	4 ± 2	4 ± 2	4 ± 2	3 ± 2	3 ± 1	12.57	0.083	
Shot accuracy (%)	37 ± 37	37 ± 32	30 ± 28	39 ± 32	44 ± 28	22 ± 27	36 ± 27	31 ± 26	7.44	0.384	
Crossing											
Successful crosses	1 ± 1	1 ± 1	2 ± 1	1 ± 1	1 ± 1	2 ± 1	2 ± 1	2 ± 1	5.44	0.606	
Unsuccessful crosses	3 ± 2	4 ± 2	3 ± 3	5 ± 2	4 ± 3	4 ± 2	4 ± 2	4 ± 2	11.95	0.102	
Total crosses	5 ± 2	5 ± 2	5 ± 3	6 ± 3	6 ± 3	6 ± 3	6 ± 2	6 ± 3	5.17	0.640	
Cross accuracy (%)	29 ± 27	15 ± 15	37 ± 28	22 ± 25	31 ± 29	29 ± 25	28 ± 21	27 ± 19	10.48	0.163	
Time in play (s)	598 ± 70	554 ± 81	554 ± 52	553 ± 60	493 ± 83	502 ± 81	551 ± 65	504 ± 61	27.66	<0.0005	E8 vs. E1

Where E1 = 00:00–14:59 min, E2 = 15:00–29:59 min, E3 = 30:00–44:59 min, E4 = 45:00–59:59 min, E5 = 60:00–74:59 min, E6 = 75:00–89:59 min, E7 = 90:00–104:59 min, E8 = 105:00–119:59 min.

4.4 DISCUSSION

The aim of this observational study was to identify the influence of the extra-time period on the technical requirements elicited during professional soccer match-play. In agreement with the hypothesis, it has been demonstrated using a within-match study design, that indices of technical performance, namely passing and dribbling, reduced in the last 15-min of extra-time. To our knowledge, this is the first study to report data concerning the influence of extra-time on professional soccer match-play; therefore such data can be used as a benchmark for future work. Given the importance of this additional competitive period in deciding success and progression in soccer tournament scenarios, this data is likely to be of interest to those responsible for the technical preparations of soccer players.

Passing performance (i.e., the number of successful and total passes) reduced by more than 20% during E8 when compared to the first half of match-play. However, the accuracy of passing remained unchanged during this time (Table 1). Although changes in formation appear to influence passing frequency (Bradley et al., 2011), our data may also indicate that the effects of match-related fatigue observed during the extra-time period of actual match-play impairs the ability to get involved with the ball rather than a player's passing proficiency *per se* (Rampinini et al., 2009). Unfortunately, physical performance measures are unavailable to substantiate this speculation and further research is needed to provide further information regarding the extra-time responses of soccer players.

Although direct comparison of our data to that reported in other performance analysis studies is limited, our findings support, and extend, previously published data identifying decrements of both physical (Rampinini et al., 2009; Carling & Dupont, 2011) and technical (Rampinini et al., 2009; Russell et al., 2013) markers in the latter stages of normal time (i.e., 90 min). In players who were deemed to be fatigued, Rampinini et al. (2009) reported between-half reductions of ~12-16% in the number of technical involvements performed per player in the Italian Serie A league. In combination with our observations, it

therefore appears that the proficiency, and number, of specific technical actions reduces as a match progresses.

Match-related fatigue could plausibly explain our observations but it is important to note that the reductions in the physical performances observed in midfield players was not previously accompanied by reduced technical performance (Carling & Dupont, 2011). To date, the effects of 120 min of soccer-specific exercise remain to be fully elucidated using controlled and repeatable experimental procedures (e.g., Soccer Match Simulation; Russell et al., 2011b). Notably, the lack of differences observed during E8 relative to the technical performances observed in E6 means that the transient changes observed during extra-time, at least in the variables assessed in this study, appear to be similar to those elicited in the latter stages of normal time (e.g., E6). It is therefore plausible that interventions that seek to counteract the deleterious effects of match-related fatigue during games that last 90 min, may also be efficacious during extra-time. However, this supposition is yet to be examined.

In previous studies where soccer match-play has been subdivided into smaller segments, statistical artefacts have been proposed to explain the identification of transient reductions in performance when compared to the opening phase of play. A desire to enforce tactical superiority (Weston et al., 2011) and residual ergogenic effects resulting from the warm-up (Russell et al., 2013) have been cited to artificially elevate the pace of play in the initial stages of a match and thereby influence subsequent comparisons to observations made during this interval. In the absence of appropriate methods of data analysis that overcome such approaches, it is important to note that the transient changes identified in E8 in this study were rarely yielded from comparison to E1 alone. In combination with the medium effect sizes for the majority of differences observed, I propose that the transient changes identified are reflective of the demands of the extra-time period and not a reflection of statistical artefacts.

Not all of the technical actions examined demonstrated a uniform response to exercise when match-play was separated into 15-min epochs; for example, ~23% of the variables examined exhibited transient changes. These findings support our previous data, albeit during 90 min of English Championship match-

play, where only two of the seven technical measures examined (namely total number of possessions and distributions performed) reduced in the last 15 min (Russell et al., 2013). However, contrary to previous literature (Rampinini et al., 2009; Carlling & Dupont, 2011), I observed a reduction in the number of successful dribbles performed in the final 15 min of extra-time. As far as I am aware, and while acknowledging the differential effects of soccer-specific exercise on technical performance (Russell et al., 2011a), no study has previously identified transient changes in dribbling performance throughout actual match-play. i attribute the identification of this finding to the longer duration of exercise examined in this study. Such data is likely to have important implications for the tactics employed by teams competing in the extra-time period.

The precise mechanisms regulating performance throughout soccer-specific exercise remain to be established and are likely to be multifaceted in nature. Notwithstanding the influence of previously mentioned factors, such as team tactics (Weston et al., 2011) and self-pacing strategies (Edwards & Noakes, 2009), it must be noted that a greater degree of variation is observed in technical performance measures (Ali et al., 2007; Russell et al., 2010) when compared to physical performance. Furthermore, although it has previously been proposed that a lack of sensitivity exists in the gross measures derived from computerised time-motion analysis studies (Carling & Dupont, 2011), performance analysis techniques have been used again, albeit with a within-match rather than within-player study design, and observed differences in the cumulative technical responses observed during 15 min epochs in matches involving professional soccer players. Furthermore, the test-retest reliability of such measures over different assessment periods has been demonstrated.

When interpreting the current findings, a number of limitations should be considered. Firstly, it is prudent to note that this data represents a within-match rather than a within-player approach. The low occurrence of games requiring extra-time, the number of eligible games that footage was available for, and the number of repeated player observations, would have yielded data with extremely low statistical power if a within-player approach has been adopted. While acknowledging this limitation, I believe that these data are the first

relating to the technical responses observed during the extra-time period in soccer. Additionally, our findings support previously published data, especially in relation to the transient variations observed (Rampinini et al., 2009). Secondly, as the ball was in play for longer in E8 than E1 (note that this was the only variable to show differences between E8 and E1 alone), one could argue that the differences observed were reflective of an interaction with this variable. However, as aforementioned, the reductions in performance observed in E8 were yielded from comparison to other epochs in addition to E1; therefore, it is unlikely that such differences reflect the time that the ball was in play. Finally, this study was a descriptive study; therefore, it was not possible to determine the cause of temporal changes in the performance of technical actions but I acknowledge the potential role of match-specific factors such as game context (e.g., score line, venue, team/opposition quality etc.) and the area of the pitch in which technical actions are performed (e.g. attacking and defensive third) (Taylor et al., 2008; Mackenzie & Cushion, 2013).

4.5 CONCLUSIONS

In summary, this study presents novel findings describing temporal patterns in the technical actions observed during 120 min of professional soccer match-play. I provide evidence demonstrating that the number of successful and total passes, number of successful dribbles and the time that the ball was in play, reduced by more than 20% in matches that required extra-time to be played; particularly in the last 15-min of extra-time. Although the current study was unable to elucidate the specific reasons for these findings, coaches and conditioning staff could use this information to inform team tactics and technical training sessions. Implementation of strategies that seek to minimise such occurrences (e.g., substitutions, aerobic and anaerobic conditioning programs and nutritional supplementation protocols etc.) should be considered; however, the efficacy of such strategies remains to be confirmed when 120 min of actual match-play is performed.

5a.0

PERFORMANCE AND PHYSIOLOGICAL RESPONSES TO 120 MINUTES OF SIMULATED SOCCER MATCH-PLAY

This work has been presented at the following academic conferences:

Harper LD, West DJ, Stevenson E, Russell M. The technical and physical performance responses to 120 minutes of soccer-specific exercise. World Congress on Science and Football 2015, Copenhagen, Denmark.

Harper LD, Stevenson E, West DJ, Russell M. Metabolic and physiological responses to 120 minutes of soccer-specific exercise. American College of Sports Medicine Annual Meeting 2015, San Diego, California, USA.

Chapter Summary

- The practitioners surveyed in chapter 3 identified 'fatigue responses' as the third most important future research area.
- In chapter 4 it was identified that technical performance reduces during ET, however; the physical and physiological performance responses during 120 min of simulated match-play have yet to be investigated.
- Using the Soccer Match Simulation, 22 participants completed 120 min of simulated match-play, with performance and physiological measures taken throughout.
- Certain aspects of physical (i.e., sprint velocities) and technical (i.e., shot velocities) performance were negatively impacted during ET. Furthermore, there were perturbations in physiological responses during ET including reduced plasma insulin, blood glucose and lactate concentrations, with concomitant increases in plasma adrenaline, IL-6, non-esterified fatty acid and glycerol concentrations.
- Diminutions in performance were accompanied by taxing of endogenous fuel sources and a shift in substrate utilisation to fat oxidation during ET

5a.1 INTRODUCTION

Soccer is a high-intensity intermittent team sport, with official matches lasting 90 min. However, in certain knockout tournament scenarios (e.g. FIFA World Cup, UEFA European Championships) an extra-time (ET) period is necessitated when the match is drawn at 90 min but an outright winner is required. At the 2016 UEFA European Championships in France, 33% of knockout matches required ET, including the final. Furthermore, in May 2016, six major cup finals in European soccer required ET (UEFA Champions League, Taça de Portugal, Spanish Copa del Rey, German DFB-Pokal, English FA Cup, and Coppa Italia). Despite the increasing prevalence of ET (the number of matches requiring ET at the FIFA World Cup has increased steadily from 25% since 2002 to 50% in 2014), there is a paucity of research on this period of play.

The performance and physiological demands of 90 min of actual and simulated soccer match-play are well known (Stolen et al., 2005; Bangsbo et al., 2007; Reilly et al., 2008). However, little data exists profiling these responses during matches of 120 min duration (i.e., inclusion of an ET period). In chapter four it was observed that indices of technical performance, in particular passing and dribbling, were negatively impacted in the last 15 min of ET. Furthermore, Russell et al., (2015b) detected reductions in total distance covered, high-intensity distance covered, and the number of sprints, accelerations, and decelerations in the last 15 min of ET compared to the last 15 min of normal time (i.e., 76-90 min) in five players during a English Premier League reserve match (Russell et al., 2015b). Lago-Penas et al., (2015) examined seven matches from the 2014 FIFA World Cup that required ET. Total distance covered and distances covered at were significantly lower in ET compared to the first 45 min of the match. Top speed was greater during the first 45 min compared to ET, and maximal running speed was lower in ET compared to both the first and second halves with concomitant increases in the time spent in low intensity activities during ET (Lago-Penas et al., (2015).

However, due to the small number of players and matches analysed, the inherent match-to-match variability that exists during actual match-play (Gregson et al., 2010) and earlier investigations not taking into factors such as team tactics (Paul et al., 2015), and self-pacing strategies (Waldron & Highton, 2014), robust conclusions on the influence of ET on performance cannot be

made. Furthermore, due to the restrictions associated with competitive match-play, assessing physiological changes (i.e., heart rate, blood sampling) is impractical and therefore the physiological responses to 120 min of soccer-specific exercise have yet to be demarcated.

To overcome variability and logistical issues a number of research groups have developed simulations of soccer match-play (i.e., Lovell et al., 2008; Bendiksen et al., 2012; Aldous et al., 2014; Page et al., 2015). These have been developed to provide a comparable exercise stimulus to actual match-play but with more robust experimental control and the ability to assess physiological and metabolic modulations during exercise. These include the Soccer Match Simulation (SMS; Russell et al., 2011b). The SMS incorporates not only the physical movement patterns of match-play but also technical actions. The SMS and the constituent technical components have been shown to be both reliable (Russell et al., 2010; Russell et al., 2011a) and valid in the same group of players (Russell et al., 2011a). The SMS has been successfully used previously to assess performance and physiological responses (Russell et al., 2011a; Russell & Kingsley, 2012) and the efficacy of nutritional interventions during 90 min of soccer-specific exercise (Russell et al., 2012; Kingsley et al., 2014).

Therefore, due to the lack of data profiling the physiological and performance responses in an ET period, the aim of this study was to assess these responses during 120 min of simulated match-play using the SMS as an analogue of soccer match-play.

5a.2 METHODS

5a.2.1 Participants

Following approval by Northumbria University's ethics committee and written informed consent being attained, 22 male university standard soccer players (age: 20 ± 2 years, mass: 73.0 ± 7.9 kg, stature: 1.79 ± 0.07 m, estimated $\dot{V}O_{2\,max}$: 54.8 ± 3.1 $ml \cdot kg^{-1} \cdot min^{-1}$) with at least one years playing experience, completed the study.

5a.2.2 Experimental Procedures

All participants completed two preliminary visits to the laboratory followed by the main trial. Each player was advised to refrain from strenuous physical activity and caffeine consumption during the 72 h preceding all testing sessions and dietary intake was recorded for the 48 h before each main trial (MicroDiet; Downlee Systems Ltd., High Peak, UK). A standardised evening meal was consumed on the night before each main trial (Energy content: 3.3 MJ, 92 g carbohydrate, 28 g fat and 37 g protein).

5a.2.3 Preliminary Testing

Following arrival at the first preliminary testing session, players emptied their bowels and bladder before body mass (BM; model 876; Seca GmbH, Hamburg, Germany) and stature (Portable Stadiometer; Holtain Ltd, Wales, UK) was measured. A controlled warm up (~20 min), including dynamic stretches and movements that progressed from low to moderate intensity, was then performed. Soccer skill practice (~5 min) preceded performance of four 20 m sprints (interspersed with 45 *s* active recovery) that progressed to near maximal speeds. Thereafter, maximal oxygen uptake was estimated (Ramsbottom et al., 1988). The second preliminary session habituated participants with the testing procedures of the main trials.

5a.2.4 Main Experimental Trial

Participants attended the laboratory at 08:15 h following an overnight fast. Upon arrival, a mid-flow urine sample was provided and urine osmolality was measured (Model 3300 Micro-Osmometer; Advanced Instruments Inc., Norwood, MA, USA). Thereafter, a resting venous blood sample was taken before a standardised breakfast providing ~10% of the individual's daily energy requirement (Rice Krispies, Kellogg's, UK, semi-skimmed milk and 500 ml of mineral water) was consumed. Body mass and stature were then measured prior to ~90 min of rest; upon which a pre-exercise blood sample was taken. Players then commenced their final preparations before performing the same standardised warm-up as used in the preliminary testing (section 5a.2.3). A five min period of passive recovery followed the end of the warm-up.

Measurements of physical and skilled performance preceded the start of exercise. Participants then performed 120 min of exercise and skills testing, consisting of two 45 min halves and two further 15 min periods (extra-time) of simulated match-play using a modified version of the Soccer Match Simulation (SMS) (Russell et al., 2011b). Post-exercise assessments of performance and body mass preceded a standardised cool down (see figure 5a.1).

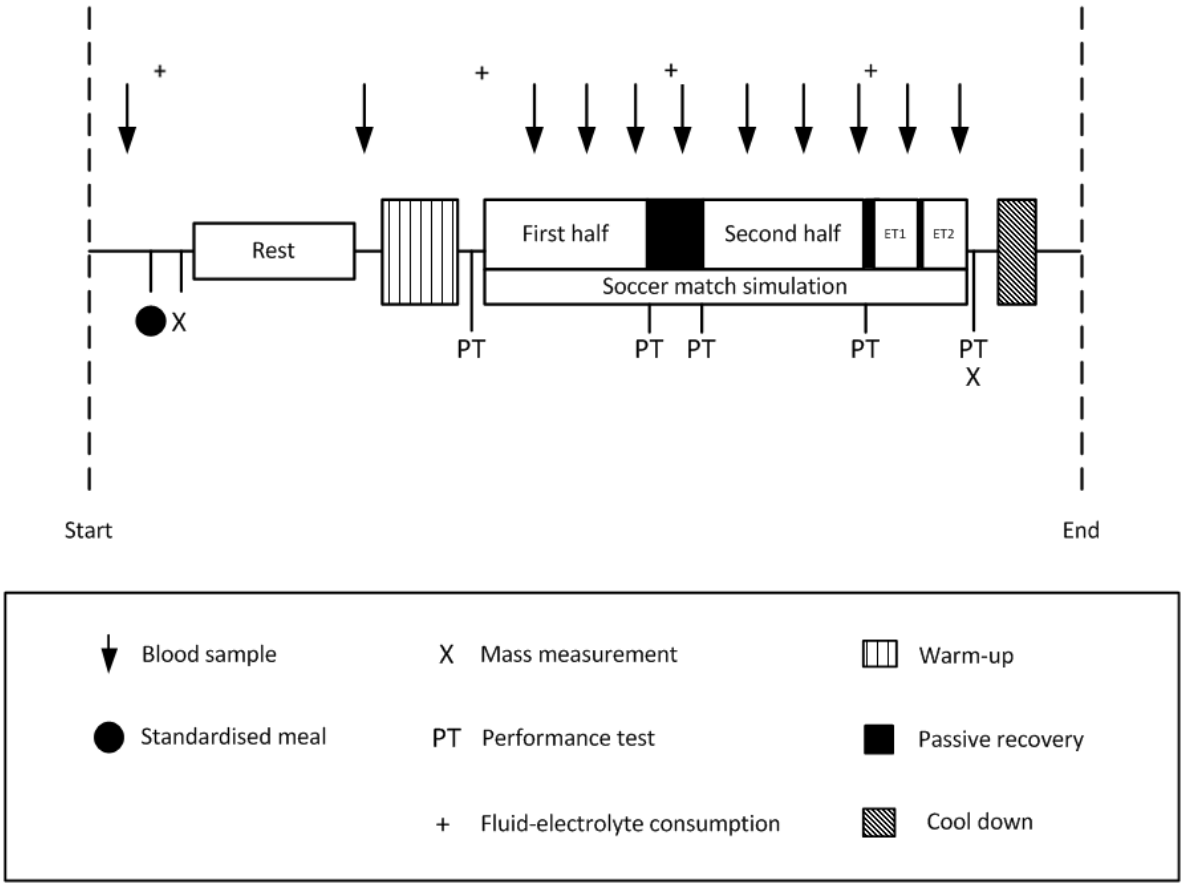

Figure 5a.1 General overview of testing day procedures

5a.2.5 Soccer Match Simulation

The modified version of the SMS required players to cover ~14.4 km (reflecting matches requiring extra-time; Russell et al., 2015b) at various running intensities, with backwards and sideward movements over a 20-m distance, while intermittently performing 15 m sprints and soccer dribbling (Russell et al., 2010). Compared to the original SMS (Russell et al., 2011b) the assessment of passing skills were omitted (such that more invasive blood samples could be taken) and extra-time was required. In line with UEFA playing regulations, a 15-min passive recovery period (half-time; HT) separated the two 45-min halves whereas a two min passive recovery period separated each extra-time half and a five min rest period preceded extra-time (Figure 5a.1). All participants consumed mineral water with the pre-exercise meal (500 ml) and before commencing the extra-time period of simulated match-play (4.5 $ml \cdot kg^{-1}$ BM).

Artificially sweetened mineral water beverages were ingested during the soccer skill component of the warm-up (4.5 ml·kg^{-1} BM) and at half-time (6 ml·kg^{-1} BM).

5a.2.6 Performance Testing

Countermovement jump (CMJ) height, repeated sprint ability and soccer shooting performance were assessed on five occasions (Performance Test, PT) throughout each trial (i.e., pre-first half (pre), post-first half, pre-second half, 90 min, 120 min; Figure 5a.1) whereas dribbling and 15 m sprint velocity were assessed throughout the SMS.

Countermovement jump height was determined using an electronic system (OptoJump Next; Microgate SRL, Bolzano, Italy). Participants performed three repetitions (with 10 *s* of recovery) with the peak value used for subsequent analyses. Timed 15 m sprint performance (Brower Timing Systems, Utah, USA) was assessed throughout the SMS and values represent a mean for each 15 min period.

Repeated sprint ability (RSA) was assessed from a standing start (from 0.3 m behind the first timing gate; Brower Timing Systems, Utah, USA) and participants performed three maximal 20 m sprints, separated by a 25 *s* period of active recovery. Soccer shooting performance was assessed using methods similar to Russell et al., (2010). Balls (Mitre Promax: size 5; Mitre Sports International, London, England) released from behind participants towards a 1.5 x 1.5-m action zone, were required to be kicked without a prior touch towards one of four randomly determined targets placed in the corners of a 7.32 x 2.44 m goal. The bouts of shooting consisted of four attempts and participants were instructed to kick with the foot that they felt was most suitable to complete the task. The layout of the dribbling test is described in general methods section 2.8.1. Participants were required to dribble a ball over a 20 m track as fast and as accurately as possible. The reliability and validity of these soccer skill tests has been determined (Russell et al., 2010).

Skilled performance was analysed according to Russell et al., (2010) from 50 Hz video footage (Sony Ltd, UK). Briefly, three outcome measures were

calculated for each skill, including: precision (distance from target), percentage success and average ball speed. Precision was determined by digitising video footage (Kinovea version 0.8.15; Kinovea Org., France) to determine the distance of the centre of the ball from the centre of the target. Success in shooting was defined by shots taken within the confines of the action zone and where the ball impacted within the goal area. The percentage of players scoring all their shots was also calculated as a parameter of shot success. During dribbling, if a cone was touched by the ball or was not completed in the required direction, the cone was considered to be unsuccessfully negotiated; success in dribbling was defined as the percentage of cones negotiated successfully. Average ball speeds were calculated for all skills (Kinovea version 0.8.15; Kinovea Org., France) and shooting variables are expressed as an average at each of the five time-points, whereas measures of dribbling performance are expressed per 15 min of exercise.

5a.2.7 Physiological Testing

Venous blood samples were taken from a cannula that was inserted in a vein in the antecubital fossa (20 gauge; BD Venflon, BD, New Jersey, USA). While participants were in a recumbent position, venous blood was drawn at rest, pre-exercise (Pre), HT, and every 15 min during exercise. Cannula patency was maintained by saline infusion (~5 ml). Blood was collected in two six ml vacutainers (EDTA and Lipid Heparin) and a two ml luer at each time-point. Vacutainers were centrifuged at 3000 revolutions·min^{-1} for 10 min (Allegra X-22R; Beckman Coulter Ltd., California, USA) with the resultant plasma subsequently frozen at -80°C. Blood from the luer was used to determine glucose and lactate concentrations (Biosen C-Line Clinic; EKF Diagnostics, Cardiff, UK).

Plasma volume changes were calculated at each time-point by measurement of haemoglobin (Hemocue Hb 201+ System; Hemocue AB, Ängelholm, Sweden) and haematocrit (Dill & Costill, 1974) and plasma osmolality was measured using freezing-point depression (Model 3300 Micro-Osmometer; Advanced Instruments Inc., Norwood, MA, USA). Urine-corrected mass changes were calculated between resting and post-exercise masses. Ratings of perceived

exertion (RPE) (Borg, 1973; Appendix 3) were determined as averages over each 15-min interval. Heart rate (HR) was continuously recorded (Polar RS400; Polar Electro, Kempele, Finland) throughout each trial.

Plasma insulin (Insulin ELISA; IBL International GmbH, Hamburg, Germany: Intra-assay CV = 1.8-2.6%), Interleukin-6 (IL-6; Interleukin-6 ELISA; IBL International GmbH, Hamburg, Germany: Intra-assay CV = 0.2-7.8%) and adrenaline (IBL Adrenalin; IBL International GmbH, Hamburg, Germany: Intra-assay CV = 6.8%) concentrations were obtained by enzyme-linked immunosorbent assays (ELISA) techniques. Plasma adrenaline concentrations represent only the Pre, 45 min, HT, 60 min, 90 min and 120 min time-points. Plasma glycerol and non-esterified fatty acid (NEFA) concentrations were measured using a clinical chemistry analyser (RX Daytona; Randox Laboratories Ltd., Co. Antrim, UK: NEFA intra-assay CV = 4.7-4.8%, Glycerol intra-assay CV = 0.9-1.3%) whereas plasma potassium concentrations were determined by atomic absorption spectrophotometry (PerkinElmer 3100 Atomic Absorption Spectrophotometer; PerkinElmer, Massachusetts, USA).

5a.2.8 Statistical Analyses

Statistical analyses were carried out using SPSS software (Version 21.0; SPSS Inc., IL, USA). All results are reported as the mean ± standard deviation (SD). The level of statistical significance was set at $p \leq 0.05$. Data was sampled for normality and repeated measures analysis of variance (ANOVA) established whether any significant effects existed in the physiological and performance responses due to time. Mauchly's test was consulted and Greenhouse–Geisser correction applied if the assumption of sphericity was violated. LSD corrected post-hoc tests were performed to isolate significant findings between time-points. Paired sample t-tests were used were only two time points existed (i.e., body mass).

5a.3 RESULTS

5a.3.1 Physiological responses

Exercise influenced blood glucose and blood lactate concentrations ($F_{(5,113)}$ = 38.539, $p \leq 0.0005$, $\eta^2 = 0.327$ and $F_{(3,65)}$ = 47.540 $p \leq 0.0005$, $\eta^2 = 0.694$, respectively). Blood glucose concentrations were lower at 120 min (3.88 ± 0.47 mmol·l^{-1}) compared to the first half (15-45 min) (4.63-4.87 mmol·l^{-1}; $p \leq 0.002$) and 75 min (4.49 ± 0.54 mmol·l^{-1}; $p = 0.015$; Figure 5a.2A). Furthermore, blood glucose concentrations were lower at 105 min (3.70 ± 0.52 mmol·l^{-1}) vs. baseline (4.29 ± 0.51 mmol·l-1; $p = 0.038$), the first half, ($p \leq 0.002$) and 60-90 min (4.30-4.49 mmol·l^{-1}; $p \leq 0.047$). Blood lactate concentrations were lower in ET (105-120 min; 3.25-3.73 mmol·l^{-1}) compared to the first half (4.94-5.42 mmol·l^{-1}; $p \leq 0.014$) and higher compared to baseline (0.79 ± 0.26 mmol·l^{-1}), pre (0.85 ± 0.21 mmol·l^{-1}), and HT (2.17 ± 1.06 mmol·l^{-1}) (all $p \leq 0.0005$, Figure 5a.2B). There were no differences in blood glucose at 90 min compared to earlier periods of exercise ($p > 0.05$; Figure 5a.2A), however; blood lactate was lower at 90 min (4.10 ± 2.13 mmol·l^{-1}) vs. 30 min (5.44 ± 2.33 mmol·l^{-1}; $p \leq 0.0005$; Figure 5a.2B).

Exercise influenced plasma insulin concentrations ($F_{(3,53)}$ = 20.206, $p \leq 0.0005$, $\eta^2 = 0.490$). Plasma insulin concentrations were lower at 120 min compared to all other time-points except 105 min ($p \leq 0.05$; Table 5a.1). Plasma insulin was also lower at 90 min vs. baseline (-40 ± 35%; $p = 0.026$), pre (-56 ± 30%; $p \leq 0.0005$), the first 30 min of exercise (-35 ± 18%; $p = 0.006$), and HT (-35 ± 26%; $p = 0.003$; Table 5a.1). Plasma adrenaline concentrations were influenced by exercise ($F_{(1,30)}$ = 31.830, $p \leq 0.0005$, $\eta^2 = 0.602$). Plasma adrenaline concentrations were higher at 120 min (12.7 ± 8.6 ng·ml^{-1}) compared to all other time points ($p \leq 0.001$) (Figure 5a.3). Plasma adrenaline was also higher at 90 min (6.0 ± 4.4 ng·ml^{-1}) compared to all other earlier time-points except at 60 min (2.7 ± 1.2 ng·ml^{-1}; $p \leq 0.028$).

Exercise influenced plasma NEFA and glycerol concentrations ($F_{(4,86)}$ = 62.593, $p \leq 0.0005$, $\eta^2 = 0.749$ and $F_{(3,71)}$ = 163.650, $p \leq 0.0005$, $\eta^2 = 0.886$, respectively). Plasma NEFA concentrations were higher at 120 min (1.5 ± 0.4 mmol·l^{-1}) and at 105 min (1.24 ± 0.4 mmol·l^{-1}) compared to all other time points

($p \leq 0.044$), except when directly compared with each other (Figure 5a.4). Plasma NEFA was also higher at 90 min (1.0 ± 0.4 $mmol \cdot l^{-1}$) when compared to all earlier time-points except HT (0.8 ± 0.4 $mmol \cdot l^{-1}$) and 75 min (0.8 ± 0.4 $mmol \cdot l^{-1}$; $p \leq 0.022$; Figure 5a.4).

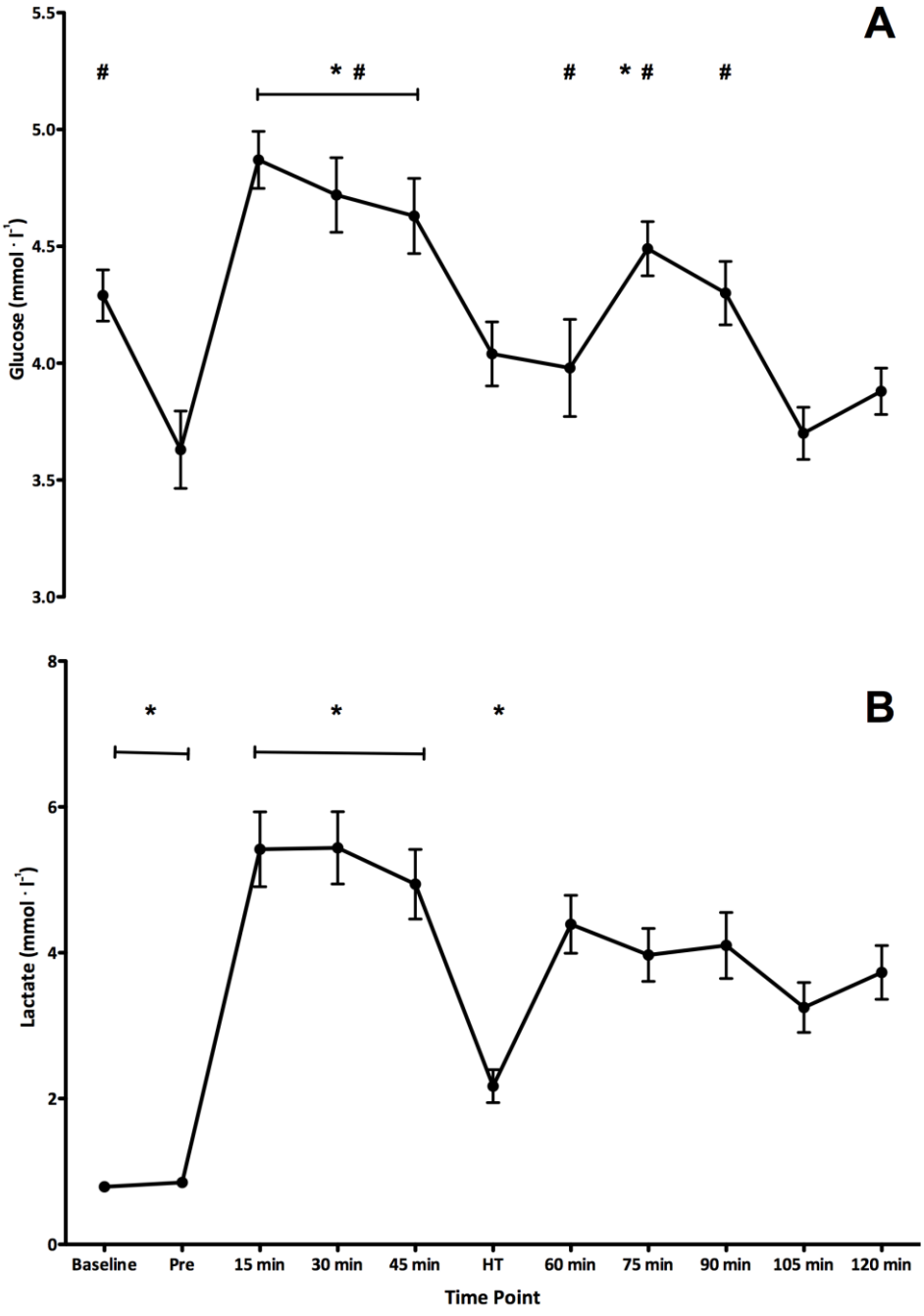

Figure 5a.2 Blood glucose (panel A) and blood lactate (panel B) data during the trial. Pre = pre-exercise. HT = half-time. * = significant difference from 120 min ($p < 0.05$). # = significant difference from 105 min ($p < 0.05$).

Table 5a.1 Physiological data during the trial. Pre = pre-exercise. HT = half-time. IL-6 = interleukin-6. RPE = rating of perceived exertion. a = significant difference from 120 min ($p < 0.05$). b = significant difference from 105 min ($p < 0.05$). c = significant difference from 90 min ($p < 0.05$).

Variable	Timing										
	Baseline	Pre	15 min	30 min	45 min	HT	60 min	75 min	90 min	105 min	120 min
Insulin ($pmol \cdot l^{-1}$)	68.2 ± 27.7 abc	104.2 ± 55.2 abc	60.1 ± 24.8 abc	59.7 ± 23.7 abc	49.9 ± 24.2 a	70.6 ± 47.6 abc	39.8 ± 9.8 a	34.7 ± 7.6 a	38.9 ± 15.6 a	33.7 ± 12.0	32.3 ± 11.3
Potassium ($mmol \cdot l^{-1}$)	4.5 ± 0.8c	4.4 ± 0.9c	4.8 ± 0.8	5.0 ± 0.8	5.0 ± 1.2	3.9 ± 0.5abc	5.0 ± 0.6	5.0 ± 0.6	5.5 ± 0.6	5.3 ± 0.9	5.0 ± 0.6
IL-6 ($pg \cdot ml^{-1}$)	3.7 ± 2.2 abc	4.5 ± 2.4 abc	5.4 ± 3.9 abc	5.4 ± 2.3 ab	7.4 ± 6.0 abc	7.2 ± 3.4 ac	6.9 ± 3.3 ac	7.1 ± 2.3 abc	9.6 ± 3.9 a	10.2 ± 3.7 a	14.3 ± 5.7
Osmolality ($mOsmol \cdot kg^{-1}$)	292 ± 12	298 ± 12	293 ± 23	295 ± 17	293 ± 14	290 ± 13	294 ± 9	297 ± 9	299 ± 10	292 ± 10	296 ± 17
RPE (AU)	-	-	12 ± 2 abc	13 ± 2 abc	14 ± 2 abc	-	13 ± 2 abc	14 ± 2 abc	15 ± 2 ab	15 ± 2 ab	17 ± 2

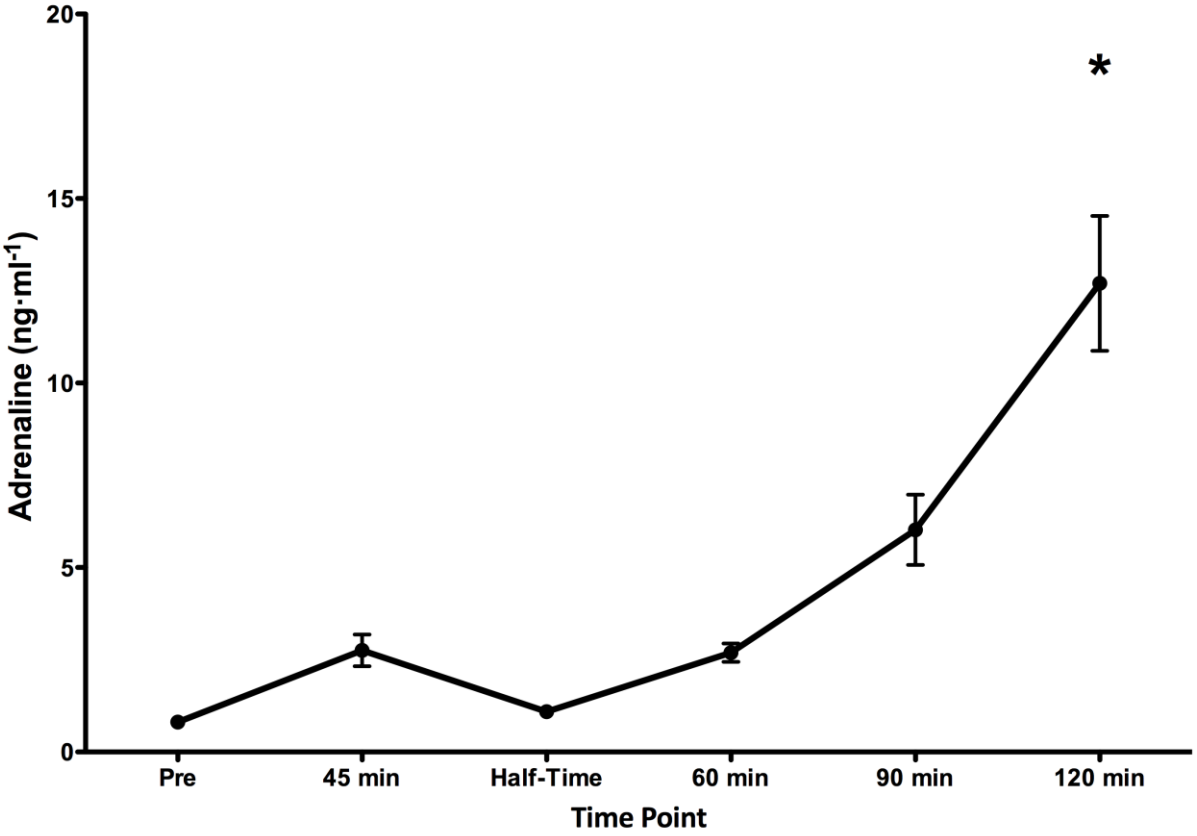

Figure 5a.3 Plasma adrenaline concentrations during the trial. Pre = pre-exercise. * = significant difference from all other time-points ($p < 0.05$).

Plasma glycerol concentrations were higher at 120 min (361 ± 95 µmol·l^{-1}) compared to all other time points ($p \leq 0.001$; Figure 5a.4). Plasma glycerol concentrations were also higher at 105 min (287 ± 78 µmol·l^{-1}) compared to all other time points, except 90 min (257 ± 63 µmol·l^{-1}; $p \leq 0.0005$; Figure 5a.4). Plasma glycerol was also elevated at 90 min compared to all earlier time-points ($p \leq 0.005$; Figure 5a.4).

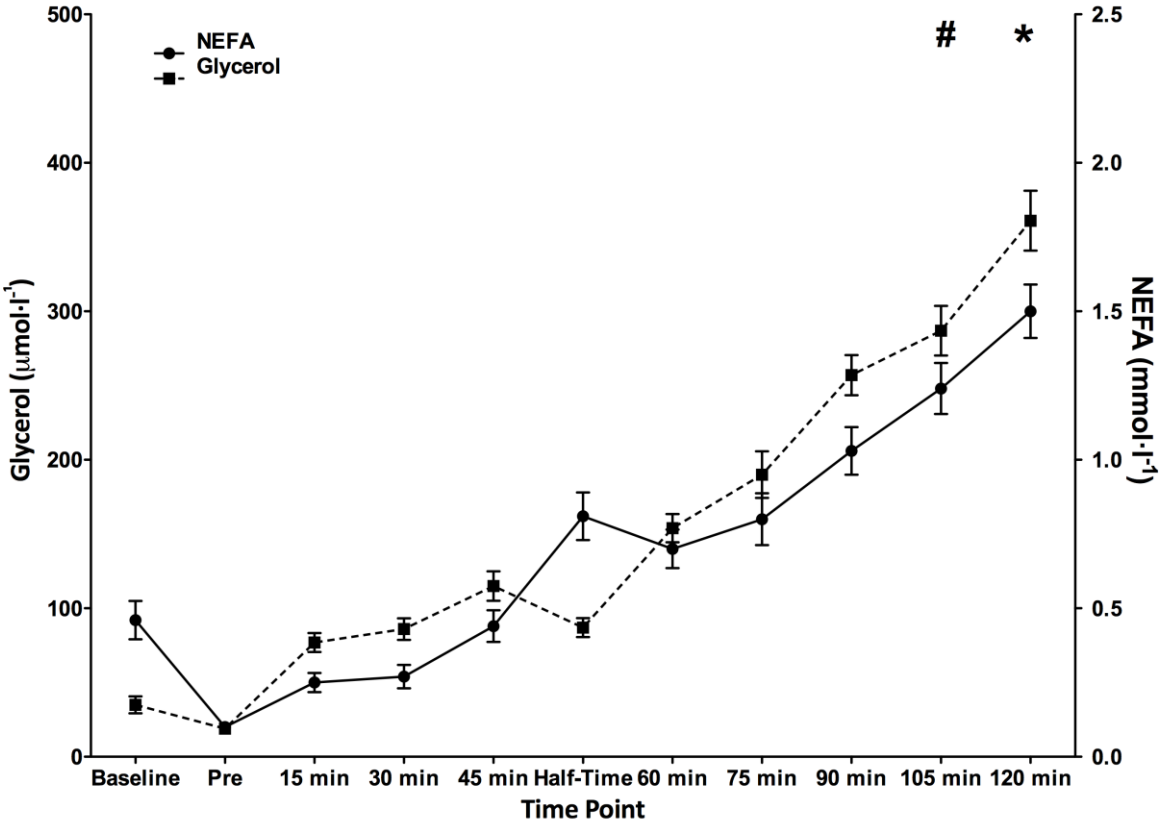

Figure 5a.4 Plasma NEFA (non-esterified fatty acids; filled circles, solid line) and plasma glycerol concentrations (filled squares, dashed line) during the trial. Pre = pre-exercise. * = significant difference from all time-points except 105 min ($p < 0.05$). # significant difference from all time-points except 120 min and except 90 min for glycerol ($p < 0.05$).

Exercise influenced plasma potassium and IL-6 concentrations ($F_{(5,107)} = 9.148$, $p \leq 0.0005$, $\eta^2 = 0.490$ and $F_{(4,90)} = 26.572$, $p \leq 0.0005$, $\eta^2 = 0.559$). Plasma potassium concentrations during ET were only significantly higher compared to HT (+25.2%; $p \leq 0.0005$; Table 5a.1). At 90 min, plasma potassium concentrations were elevated vs. baseline (+18 ± 11%; $p \leq 0.0005$), pre (+19 ± 15%; $p = 0.001$), and HT (+29 ± 9%; $p \leq 0.0005$; Table 5a.1). Plasma IL-6 concentrations were elevated at 120 min compared to all other time-points except 105 min ($p \leq 0.0005$; Table 5a.1). At 90 min, plasma IL-6 concentrations were higher compared to all earlier time-points, except at 30 min ($p \leq 0.018$; Table 5a.1). Exercise did not influence plasma osmolality ($F_{(3, 72)} = 0.948$, $p = 0.431$, $\eta^2 = 0.043$; Table 5a.1); however, body mass reduced post-exercise

compared to pre-exercise (71.6 ± 7.9 vs. 73.4 ± 8.0 kg; p ≤ 0.0005). Plasma volume changes occurred during exercise (osmolality ($F_{(4,77)}$ = 4.158, p = 0.005, η^2 = 0.165), however; there were no changes during ET.

Exercise influenced RPE ($F_{(3,58)}$ = 59.701, p ≤ 0.0005, η^2 = 0.740). During ET RPE were elevated compared to all other time points (p ≤ 0.0005) except 105 min vs. 90 min (Table 5a.1). RPE was also elevated at 90 min compared to all earlier time-points (p ≤ 0.0005; Table 5a.1) Both mean ($F_{(4,86)}$ = 2.994, p = 0.022, η^2 = 0.125) and peak HR ($F_{(3,58)}$ = 4.763, p = 0.006, η^2 = 0.185) were influenced by exercise. Mean HR was higher in the last 15 min of ET compared to all other time points except the first 15 min of ET (p ≤ 0.045; Table 5a.2). Peak HR was increased in the last 15 min of ET compared to all other time-points except the first 15 min of exercise (p ≤ 0.030; Table 5a.2). Notably, differences in mean HR not apparent from 90-105 min vs. earlier periods of exercise or 75-90 min vs. earlier periods of exercise (both p > 0.05; Table 5a.2). However, peak HR was higher in the last 15 min of normal time (i.e., 75-90 min) when compared to 15-30 min (+1 ± 2%; p = 0.039) and 45-60 min (+1 ± 1%; p = 0.004) (Table 5a.2).

Table 5a.2 Physiological and technical performance data during the trial. HR = heart rate. a = significant difference from 105-120 min (p < 0.05).

Variable	Timing							
	0-15 min	15-30 min	30-45 min	45-60 min	60-75 min	75-90 min	90-105 min	105-120 min
Peak HR (beats·min^{-1})	184 ± 11	183 ± 11a	184 ± 10a	183 ± 10a	185 ± 10a	185 ± 9a	184 ± 9a	187 ± 10
Mean HR (beats·min^{-1})	161 ± 13a	159 ± 15a	159 ± 16a	160 ± 11a	161 ± 14a	161 ± 12a	162 ± 12	164 ± 13
Dribbling speed (m·s^{-1})	3.24 ± 0.33	3.17 ± 0.24	3.14 ± 0.21	3.22 ± 0.17	3.24 ± 0.18	3.24 ± 0.30	3.14 ± 0.22	3.13 ± 0.29
Dribbling precision (cm)	40.4 ± 8.0a	37.2 ± 7.9	37.4 ± 7.5	33.7 ± 7.3	32.5 ± 8.0	34.7 ± 9.2	34.1 ± 8.2	34.1 ± 7.1
Dribbling success (%)	90 ± 7	89 ± 8	91 ± 11	93 ± 8	86 ± 15	86 ± 13	88 ± 11	90 ± 8

5a.3.2 Physical performance responses

Exercise reduced 20 m sprint velocities ($F_{(2,34)}$ = 12.869, p ≤ 0.0005, η^2 = 0.380) with reduced velocities at 120 min (5.67 ± 0.48 m·s^{-1}) compared to all other time points (p ≤ 0.038; Figure 5a.5). Sprint velocities over 20 m at 90 min (5.92 ± 0.31 m·s^{-1}) were only lower compared to baseline (6.14 ± 0.27 m·s^{-1}; p ≤ 0.0005; Figure 5a.5). Exercise also influenced 15 m sprint velocities ($F_{(3,72)}$ = 40.180, p ≤ 0.0005, η^2 = 0.657). Sprint velocities over 15 m were depressed during ET (both 90-105 and 105-120 min; 5.1 ± 0.3 m·s^{-1} and 4.9 ± 0.3 m·s^{-1}, respectively) compared to the rest of exercise (p ≤ 0.002; Figure 5a.6). During 75-90 min, 15 m sprint velocities (5.2 ± 0.3 m·s^{-1}) were also lower compared to all earlier periods of exercise (p ≤ 0.034). Countermovement jump heights were influenced by exercise ($F_{(2,46)}$ = 3.977, p = 0.023, η^2 = 0.159), however; there were no differences at 120 min compared to any other time-point (p > 0.05; Table 5a.3). Furthermore, there were no differences at 90 min vs. any other time-point (p > 0.05; Table 5a.3). Notably, both 20 m sprint velocities and CMJ heights were depressed following HT (i.e., pre-second half) compared to both baseline (-4 ± 2% and -5 ± 6%, respectively) and post-first half (-2 ± 2% and -6 ± 5%, respectively; p ≤ 0.05; Table 5a.3).

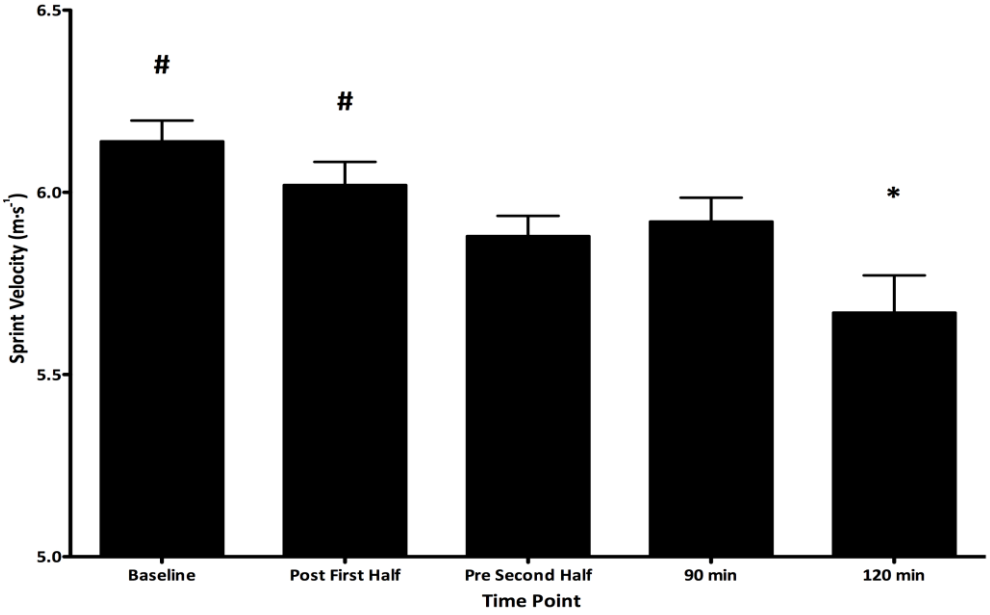

Figure 5a.5 20 m sprint velocities during the trial. * = significant difference from all time-points except pre second half (p < 0.05). # = significant difference from pre second half (p < 0.05).

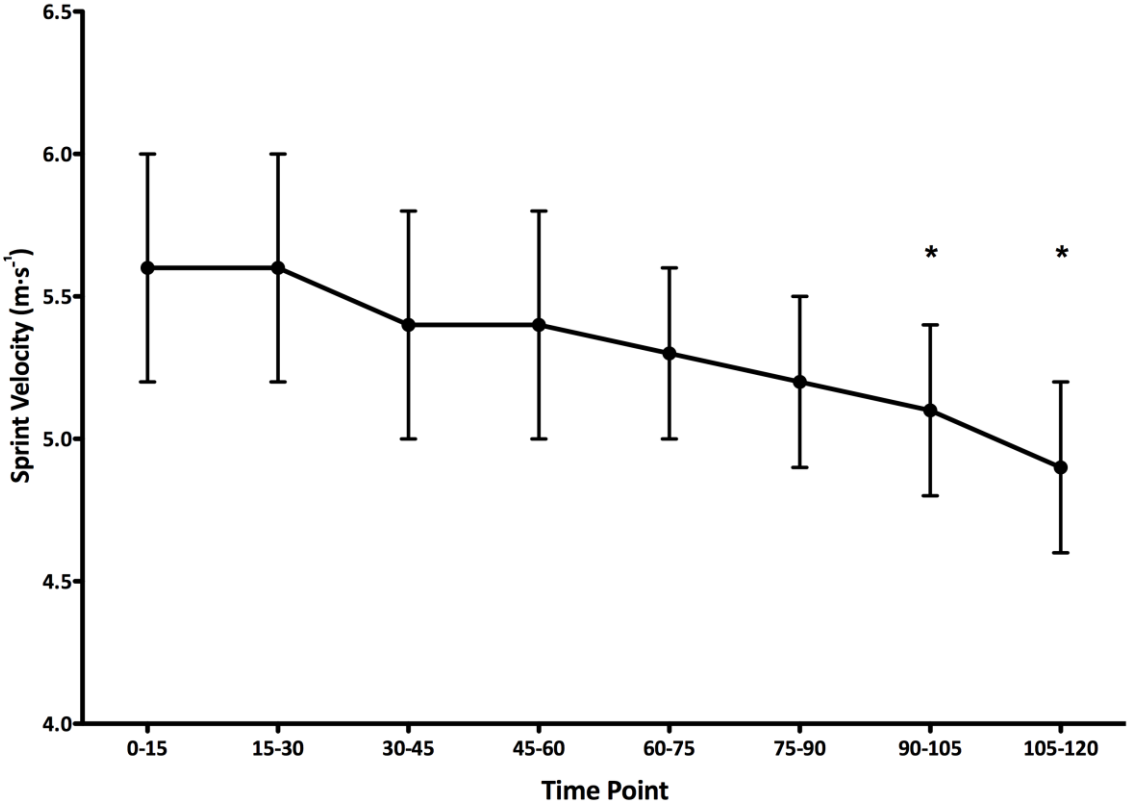

Figure 5a.6 15-m sprint velocities during the trial. * = significant difference from all earlier time-points ($p < 0.05$).

Table 5a.3 Physical and technical performance data from the trial. a = significant difference from 120 min ($p < 0.05$).

Variable	Timing				
	Pre	Post-first half	Pre-second half	90 min	120 min
Jump height (cm)	33.7 ± 4.8a	34.7 ± 5.3a	32.6 ± 5.6	33.9 ± 6.1	33.2 ± 6.1
Shot precision (cm)	124.0 ± 52.4	116.0 ± 50.9	136.9 ± 64.1	143.4 ± 52.4	119.8 ± 63.1
Shot success (%)	67 ± 22	69 ± 20	74 ± 25	75 ± 20	66 ± 20

5a.3.3 Technical performance responses

Shot precision ($F_{(4,84)}$ = 1.267, p = 0.293, η^2 = 0.057) and success ($F_{(4,84)}$ = 0.984, p = 0.413, η^2 = 0.045) were unaffected by exercise (Table 5a.3) whereas shot velocity reduced ($F_{(4,84)}$ = 3.121, p = 0.019, η^2 = 0.129). Shot velocities at 120 min (17.6 ± 2.5 m·s^{-1}) were slower compared to all time-points except pre-second half (17.9 ± 2.5 m·s^{-1}; p ≤ 0.017; Figure 5a.7). Shot velocities at 90 min (18.4 ± 2.3 m·s^{-1}) were not different to earlier time-points (p > 0.05; Figure 5a.7).

There was no influence of exercise on dribble success ($F_{(4,83)}$ = 1.642, p = 0.172, η^2 = 0.073) or dribble speed ($F_{(5,102)}$ = 0.076, p = 0.081, η^2 = 0.089) (Table 5a.2). Dribble precision was affected by exercise ($F_{(4,80)}$ = 6.813, p ≤ 0.0005, η^2 = 0.245), with more precise dribbles during the last 15 min of ET than the first 15 min of normal time (+16 ± 11%; p = 0.010; Table 5a.2). Dribbles were also more precise in the last 15 min of normal time vs. the first 15 min (+14 ± 14%; p = 0.002; Table 5a.2).

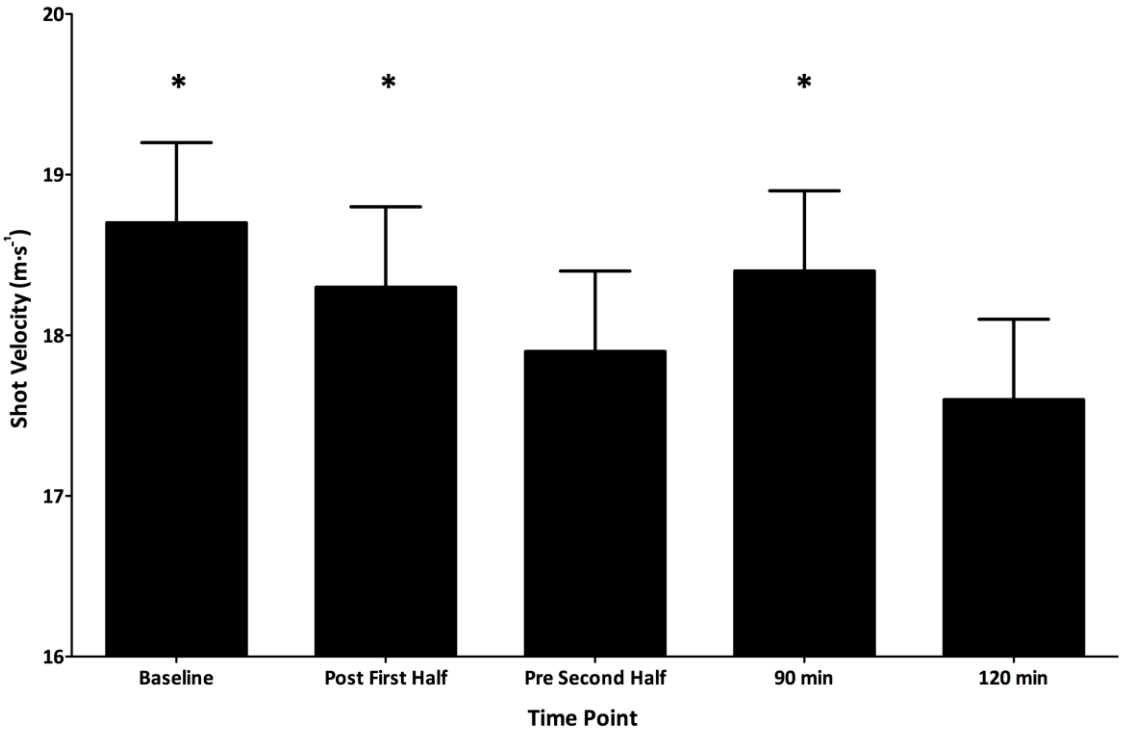

Figure 5a.7 Shot velocities during the trial. * = significant difference from 120 min (p < 0.05).

5a.4 DISCUSSION

The aim of this chapter was to profile the performance and physiological responses during 120 min of simulated soccer-match play. Extra-time causes further decrements in performance, and perturbations in physiological and metabolic responses compared to the previous 90 min of exercise. Indeed, reductions in sprint performance were accompanied by elevated plasma IL-6, adrenaline, NEFA, and glycerol concentrations, and decreased plasma insulin and blood glucose and lactate concentrations during ET. These changes are indicative of a shift in substrate utilisation during ET towards predominately fat oxidation. This has implications for high-intensity intermittent exercise, which is reliant on substrate level phosphorylation as a primary source of energy (Reilly, 1997).

Sprint velocities over 15-m and 20-m were lower during ET and at 120 min compared to all other time-points. This represents a novel finding that ET causes further perturbations in the ability to maintain sprint speed during simulated match-play. This finding corroborates data from actual match-play requiring ET (Lago-Penas et al., 2015; Russell et al., 2015b). Lago-Penas and colleagues observed lower top speeds during the ET period of professional match-play compared to the first 45 min, and lower maximal running speed in ET compared to both the first and second halves (Lago-Penas et al., 2015). Furthermore, Russell et al. detected reductions in total distance covered and high-intensity distance covered in the last 15 min of ET compared to the last 15 min of normal time during an English Premier League Reserve cup match (Russell et al., 2015b).

Although sprint velocities were tempered during ET, there was no effect of this period on CMJ height. Although previous findings from studies investigating changes in jump height following 90 min of simulated soccer-match play are equivocal (Thorlund et al., 2009; Robineau et al., 2012; de Hoyo et al., 2016; Stone et al., 2016), the findings from this thesis suggest that players are able to preserve jump performance throughout simulated match-play (no changes were detected at 90 min vs. other time-points either). Nonetheless, Russell et al. observed dampened CMJ performance in the recovery period (+24 and +48 h) following a match requiring ET (Russell et al., 2015b). As mentioned in chapter 3, investigations into the time course of recovery following ET are required.

Notably, jump heights were lower following a 15 min passive HT period compared to baseline and post-first half. Half-time has been previously shown to have deleterious effects on soccer-specific performance (Mohr et al., 2005; Weston et al., 2011; Lovell et al., 2013), with putative mechanisms including a decrease in muscle and core temperature (Mohr et al., 2004), and changes in glycaemia (Russell et al., 2015c). Interventions that attenuate these decrements in performance warrant further investigation (Russell et al., 2015c). Furthermore, the influence of the five min break separating normal time and ET on CMJ performance should also be assessed.

Dribbling performance was well maintained during ET compared to the prior 90 min, with the more precise dribbles during ET compared to the first 15 min of exercise being observed. These findings support data during 90 min of simulated match-play (Russell et al., 2011) and also chapter 4, as although the total number of dribbles reduced; actual dribble proficiency (i.e., accuracy) was not affected in chapter 4. Therefore it would seem that players are able to maintain dribble proficiency *per se* throughout an ET period (and even become more precise). The participants were able to maintain dribble speed throughout the 120 min highlighting that a *speed-accuracy trade-off* is not the reason for the improved precision.

This is the first study to investigate the influence of an ET period on aspects of metabolism. Findings up to 90 min were similar to previous investigations, however; ET caused further perturbations in these responses. This is expected due to the prolonged nature of the exercise and from previous findings during other modalities of exercise lasting 120 min (Hargreaves et al., 1996; Sprenger et al., 2013; Williams et al., 2015). However, this is the first study to demonstrate these changes using a soccer-specific exercise protocol.

Interleukin-6 concentrations were elevated during ET. Interleukin-6 is a pleiotropic cytokine and myokine, with a plethora of mechanistic roles in homeostatic negative and positive feedback loops (Ball, 2015). Indeed, contractile activity of the muscle leads to systemic release of IL-6 (Reihmane & Dela, 2014). Previous research has demonstrated a role for increased IL-6 concentrations in hepatic glycogenolysis through a ‘contractile factor’ (Keller et al., 2001; Pedersen & Febbraio, 2008). However, more recent research would suggest that IL-6 is not involved in the mobilisation of liver glucose stores

(O'Neill et al., 2013), and is actually a negative regulator of hepatic glucose output (Dent et al., 2016). Although the effect of IL-6 on liver glycogen remains equivocal, it is known that increased IL-6 concentrations are linked to low availability of intramuscular glycogen (Keller et al., 2001; Steensberg et al., 2001) and also to increased fat metabolism through the augmentation of the sympathoadrenal system (Wolsk et al., 2010; Ball, 2015). Other metabolic data collected in the present investigation would corroborate this, with elevated plasma adrenaline, glycerol and NEFA concentrations and dampened plasma insulin and blood lactate concentrations during ET.

Adrenaline accelerates glycogenolysis through its downstream activation of phosphorylase α (Chasiotis et al., 1983; Watt et al., 2001) as well as acting as a stimulator of hormone sensitive lipase (HSL), a major enzyme involved in lipolysis (Watt & Spriet, 2004). As both insulin and lactate are inhibitors of HSL, the observed decrease in these metabolites during ET further strengthens the evidence for a shift in substrate utilisation in ET, with increased reliance on fat oxidation to fuel the exercise. Furthermore, low glycogen levels have been associated with impaired sprint performance during soccer match-play (Krustrup et al., 2006; Rollo, 2014). This is possibly due to a depressed muscle sarcoplasmic reticulum calcium release rate, which contributes to reductions in force production and fatigue when muscle glycogen levels are diminished (Ortenblad et al., 2011; Gejl et al., 2014). Despite an increased taxing of muscle glycogen, blood glucose concentrations remained dampened during ET, with 50% of participants exhibiting values indicative of hypoglycemia (<3.6 $mmol.l^{-1}$; Cryer, 2003). Reductions in blood glucose have been shown to impair physical output (Welsh et al., 2002; Winnick et al., 2005; Ali et al., 2007) and cognitive function (Benton, 2002; Benton & Nabb, 2003), which are crucial to successful soccer performance. Therefore these metabolic perturbations during ET may explain the reductions in performance observed.

Although there were no changes in plasma osmolality during ET compared to the previous 90 min, participants body mass reduced by ~2.5% at 120 min vs. baseline. This is despite following an ecologically valid hydration strategy. As this is above the 2% threshold considered detrimental to soccer-specific performance (Laitano et al., 2014), optimising hydration strategies in matches that may require ET is crucial. Moreover, changes in body mass from 90 min to

120 min should also be assessed to delineate what the exact losses are in the ET period. The drop in body mass was accompanied by increased mean and peak HRs in the last 15 min of ET. As the intensity of exercise remained constant throughout exercise, this is indicative of cardiovascular drift and suggests progressive dehydration during ET. Furthermore, RPE values were higher in ET compared to during 90 min. The RPE scale (Borg, 1982) has been linked to afferent feedback from the cardiovascular, musculoskeletal and respiratory systems (Crewe et al., 2008), and is a sensitive indicator of fatigue perception (Eston & Williams, 1988). Therefore, it would seem that participants find ET harder than during 90 min, despite the exercise intensity remaining the same.

5a.5 CONCLUSIONS

In conclusion, an ET period has negative implications for both performance and physiology, with reductions in sprint performance, increased perception of effort, progressive dehydration, increased taxing of endogenous fuel sources and a shift to fat oxidation in the additional 30 min. Future investigations are required to investigate the effect of interventions that better maintain performance and prevent perturbations in the physiological and metabolic responses (i.e., nutritional interventions).

5b.0

TEST-RETEST RELIABILITY OF PHYSIOLOGICAL AND PERFORMANCE RESPONES TO 120 MINUTES OF SIMULATED SOCCER MATCH-PLAY

This work has been published in a peer reviewed journal:

Harper LD, Hunter R, Parker P, Goodall S, Thomas K, Howatson G, West DJ, Stevenson E, Russell M. Test-retest reliability of physiological and performance responses to 120 minutes of simulated soccer match-play. J Strength Cond Res [published ahead of print]

Chapter Summary

- The Soccer Match Simulation (SMS) has been previously shown to be reliable during 90 min of exercise. However, the reliability of the responses gathered have not been assessed over 120 min.
- While assessing the same variables measured during chapter 5a plus core temperature (T_{core}) and Creatine Kinase, participants completed the SMS twice under standardised conditions.
- All variables except blood lactate demonstrated no systematic bias between trials. During the last 15 min of ET, test-rest reliability was moderate-to-strong for 20 m sprint speed, countermovement jump height, dribble speed and blood glucose, and very strong for T_{core}. Moderate reliability was demonstrated for 15 m sprint speed, dribble precision, plasma insulin, Creatine Kinase, interleukin-6, non-esterified fatty acids, glycerol, and blood lactate.
- The SMS is a reliable protocol for measuring responses across a full 120 min of soccer-specific exercise.

5b.1 INTRODUCTION

Soccer is a high-intensity intermittent team sport, requiring players to perform a number of physical and technical actions for the duration of a match. For the past five decades soccer research has grown exponentially and a plethora of publications exist investigating the performance and physiological demands of soccer match-play (Mohr et al., 2005; Stolen et al., 2005). Furthermore, investigations into the efficacy of nutritional and training interventions on soccer performance are popular (Wells et al., 2014; Kingsley et al., 2014; Russell et al., 2015c). However, due to the inherent match-to-match variability associated with soccer it is difficult to make meaningful inferences about the effectiveness of interventions during actual match-play (Gregson et al., 2010). As such, a number of laboratory based protocols that replicate the demands of soccer match-play have been developed utilising motorised (Drust et al., 2000; Page et al., 2015) and non-motorised treadmills (Aldous et al., 2014). However, despite being both valid and reliable, such protocols lack some ecological validity due to the unidirectional nature of treadmills, and the inability to incorporate skill actions (i.e., ball dribbling).

The Soccer Match Simulation (SMS) is a free-running laboratory protocol adapted from the Loughborough Intermittent Shuttle Test (Russell et al., 2011b) that has been shown to be valid and reliable when profiling performance (sprint speeds and skill performance) and physiological (heart rate, blood lactate, and sweat losses) responses to <90 min of simulated soccer match-play (Russell et al., 2010; Russell et al., 2011a). The SMS integrates movement demands analogous with soccer match-play including ball dribbling, backwards and sideways movement, and frequent changes of direction (Russell et al., 2011b). Although recent research using treadmill-based protocols has highlighted that the mechanical response to soccer-specific exercise is similar to match-play (Azidin et al., 2015; Page et al., 2015), players are unlikely to achieve maximum speeds during this type of exercise. Furthermore, as ball dribbling and changes of direction have been shown to elicit a larger energy cost than when no ball is present (Reilly, 1984) or exercise is of a unidirectional nature (Reilly, 1997; Stevens et al., 2015); inclusion of these actions may more closely represent match-play than a treadmill-based protocol.

The SMS has been successfully utilised to assess performance and physiological responses (Russell et al., 2011a; Russell & Kingsley, 2012) and the efficacy of nutritional interventions during 90 min of soccer-specific exercise (Russell et al., 2012; Kingsley et al., 2014). Although soccer matches have a typical duration of 90 min, tournament scenarios may require an additional 30 min period termed extra-time (ET). However, to date, no studies have reported the reliability of responses across the full duration of matches requiring ET. Such studies are necessary to facilitate controlled investigations into the responses observed throughout prolonged soccer-specific exercise.

Reductions in physical performance capacity and the number of dribbles and passes performed during the ET period of actual soccer match-play have previously been identified (chapter 4; Russell et al., 2015). In five professional reserve team players, diminutions in total and high-intensity distance covered and the number of accelerations and decelerations were observed (Russell et al., 2015).

In summary, as the SMS has been shown to be a reliable protocol during soccer-specific exercise (i.e., <90 min), I aimed to confirm the reliability of responses to extended periods of simulated soccer match-play (i.e., 120 min). Notably, the reliability of soccer-specific protocols is typically assessed with limited time resolution (i.e., not in frequent time intervals that are typically used to disseminate data); thus, I employed a greater frequency of measurements across 120 min in the present investigation. Our second aim was to investigate the influence of ET on performance and physiological responses. It was hypothesised that the SMS would demonstrate good reliability for 120 min and that an ET period would influence performance and physiological responses.

5b.2 METHODS

5b.2.1 Experimental Approach to the Problem

To confirm the reliability of responses to the SMS across 120 minutes of soccer-specific exercise, ten male university-standard soccer players completed a simulated soccer match with performance and physiological measurements taken at regular intervals. The dependent variables included in this study were indices of exercise intensity and performance (i.e., 15 m and 20 m sprint speeds, countermovement jump (CMJ) height, heart rate (HR), rating of perceived exertion (RPE), and dribble speed, precision and success); physiological measures (i.e., blood glucose and lactate, plasma Creatine Kinase (CK), insulin, non-esterified fatty acids (NEFA), glycerol, and interleukin-6 (IL-6), and core temperature (T_{core})); and hydration status (i.e., urine osmolality and body mass changes).

5b.2.2 Subjects

The study received ethical approval from the Faculty of Health and Life Sciences Ethics Committee at Northumbria University. Ten male university-standard soccer players (age: 22 ± 3 years, mass: 77.2 ± 7.8 kg, stature: 1.80 ± 0.06 m, estimated $\dot{V}O_{2\ max}$: 55.7 ± 1.5 $ml \cdot kg^{-1} \cdot min^{-1}$) provided written informed consent. Participants had finished their competitive season approximately two weeks before study commencement but were still engaged in unstructured training to maintain fitness.

5b.2.3 Design

Preliminary visits preceded main trials to estimate $\dot{V}O_{2max}$ (Ramsbottom et al., 1988) and to perform a full 120 min habituation of the protocol and all study day procedures. Two standardised main trials separated by 7 ± 1 days were then completed, with each participant starting both trials at the same time of day (~07:45 h). Environmental conditions were similar between trials (temperature: 19.7 ± 0.4°C, humidity: 36 ± 8%; both $p > 0.05$). Participants consumed the same evening meal and refrained from strenuous activity and caffeine consumption in the 24 h preceding each main trial. Adherence to these criteria was assessed by the administration of a food and physical activity diary for the

24 h prior to each trial. Upon waking (~3.5 h prior to exercise), and following an overnight fast, participants swallowed a telemetric pill (HT150002, CorTemp, HQ Inc., USA) to allow for continuous measurement of T_{core} using a reliable device (Byrne & Lim, 2007). At the laboratory, a mid-flow urine sample and a resting capillary blood sample was taken before participants consumed a standardised breakfast that provided 10% of daily energy requirements (cereal and semi-skimmed milk with 500 ml of a fluid-electrolyte beverage; Highland Spring, UK). Body mass and stature (Seca GmbH & Co., Germany) were then measured.

Capillary and venous blood samples were taken after a ~90 min rest period following breakfast. A standardised warm-up (including channel drills, dynamic stretching and skill performance) was then performed, during which participants consumed 200 ml of the fluid-electrolyte beverage. After five min of passive rest, participants performed three CMJ's separated by 10 *s* passive recovery and three 20 m sprints interspersed with 25 *s* of active recovery. These measures were repeated on a further four occasions: post-first half, pre-second half, 90 min and 120 min.

Using a modified version of the SMS (i.e., the inclusion of an ET period; Russell et al., 2011b), participants completed 120 min of intermittent exercise and skills testing consisting of two 45 min halves and two additional 15 min periods (ET). Directed by audio signals, the SMS required the participants to cover ~14.4 km (reflecting an actual match requiring ET; Russell et al., 2015)) while intermittently performing 15 m sprints and 18 m ball dribbles (assessed for precision, percentage success, and average speed (Russell et al., 2010). Participants covered 5.05 km in the first and second half and 4.3 km in ET. Dribbling performance was expressed as an average per 15 min of exercise (epochs; E*N*): 0-15 min (E1), 16-30 min (E2), 31-45 min (E3), 46-60 min (E4), 61-75 min (E5), 76-90 min (E6), 91-105 min (E7) and 106-120 min (E8).

A passive 15 min half-time (HT) period separated the two 45 min halves where participants consumed 500 ml of the fluid-electrolyte beverage. Five min of rest followed the end of normal time and a two min passive period separated each half of ET. Body mass assessment and consumption of 300 ml of the fluid

electrolyte beverage with two 66 g energy-free electrolyte gels preceded the start of ET.

Capillary blood samples were collected in 20 µl heparinised tubes (at rest, pre-exercise, HT and at the end of each epoch; E1-E8) and analysed for blood glucose and lactate concentrations (Biosen C-Line; EKF-diagnostic GmBH, Germany CV: both 1.5%). Venous blood samples were collected *via* venepuncture in 6 ml lithium-heparin and EDTA vacutainers at pre-exercise, HT, 90 min, and 120 min. Following centrifugation at 3000 x *g* at 4°C the plasma was aspirated and immediately frozen at −80°C and subsequently analysed for concentrations of insulin (Insulin ELISA; IBL International GmbH, Germany; CV: 1.8%), IL-6 (Interleukin-6 ELISA, IBL International GmBH, Germany; CV: 3.4%), creatine kinase (Cobas 8000; Roche Diagnostics; USA; CV%: 0.7%), NEFA, and glycerol (both Randox Daytona^{+}; Randox Laboratories Ltd., UK; CV's: 4.7 and 0.8%, respectively) to measure physiological stress and substrate utilisation.

Urine osmolality (Advanced Model 3300 Micro-Osmometer; Advanced Instruments Inc., USA; CV: 1.5%), urine-corrected mass changes, RPE (Borg, 1982; Appendix 3), and T_{core} were recorded during each trial. Environmental conditions were measured during exercise (Technoline WS-9032; Technotrade GmbH, Germany) and HR was continuously recorded (Polar RS400; Polar Electro, Finland). A mid-flow urine sample was collected and body mass measured, post-exercise.

5b.2.4 Statistical Analysis

Statistical analyses were carried out using SPSS Statistics software (IBM Inc., USA) with statistical significance accepted at $p \leq 0.05$. Data are reported as mean ± standard deviation (SD). Statistical power was calculated using commercially available software (GPower v3.1, Germany) and a sample size of ten was deemed sufficient for ≥ 80% power to detect statistical differences in T_{core}, blood glucose, and 15 m sprint speed. As a number of different methods have been employed in previous investigations, with each method providing distinct characteristics, a range of statistical methods were utilised to assess test-retest reliability of the variables measured. Following assessments of normality and equal variance, two-way repeated measures analyses of variance

were performed for data expressed over multiple time-points to assess variability over time and between trials to allow for detection of systematic bias. LSD corrected *post-hoc* tests were employed where appropriate. As recommended by (Hopkins, 2000), absolute reliability was determined using typical error (TE, raw units) and coefficient of variation (CV, %), and relative reliability was assessed using Pearson's correlation coefficient (*r*). Correlations of r = 0.3-0.5, 0.5-0.7 and > 0.7 were considered moderate, strong, and very strong, respectively (Hopkins, 2000). CVs < 10% were considered as showing good absolute reliability (Atkinson & Nevill, 1998). Effect sizes (ES) were calculated for performance and physiological responses across 120 min using Cohen's *d*, with thresholds of 0.2, 0.5 and 0.8 considered as small, medium and large ES (Fritz et al., 2012).

5b.3 RESULTS

5b.3.1 Reliability of Performance Responses

Relative (i.e., *r*) and absolute (i.e., CV%, TE) reliability statistics are presented in Figure 5b.1 and Tables 5b.1 and 5b.2. The majority of performance variables demonstrated good absolute reliability (CV ≤ 7.2%); with only dribble precision and success showing higher CVs (≤ 13.3%) across the 120 min (Tables 5b.1 and 5b.2). CMJ height, 20-m sprint speeds, and dribble speeds were the most reliable performance variables and correlated very strongly ($r \geq 0.71$) (Tables 5b.1 and 5b.2). Sprint speeds over 15-m showed weak to strong correlations ($r \geq 0.34$) (Table 2) throughout exercise. Dribble precision demonstrated moderate to very strong relationships during seven out of eight epochs ($r \geq 0.30$) (Table 5b.2).

Table 5b.1 Performance and physiological data during trials 1 and 2 (mean ± SD). CMJ = countermovement jump. NEFA = non-esterified fatty acids. CV = coefficient of variation. TE = typical error. *r* = Pearsons correlation coefficient. a = p ≤ 0.05. b = significant difference from 120 min. c = significant difference from pre-second half (p ≤ 0.05).

Variable		Timing				
		Pre-Exercise	**Post-First Half**	**Pre-Second Half**	**90 min**	**120 min**
20-m sprint speed (s)	Trial 1	3.21 ± 0.13	3.33 ± 0.11	3.38 ± 0.12	3.40 ± 0.14	3.52 ± 0.25
	Trial 2	3.22 ± 0.15	3.31 ± 0.14	3.39 ± 0.18	3.42 ± 0.18	3.54 ± 0.40
	Mean	3.22 ± 0.13 d e	3.32 ± 0.12 d e	3.39 ± 0.15	3.41 ± 0.16	3.53 ± 0.32
	CV(%)	0.5	1.1	1.0	2.2	3.5
	TE	0.05	0.08	0.08	0.16	0.25
	r^2	0.92 a	0.84 a	0.88 a	0.50 a	0.50 a
CMJ height (cm)	Trial 1	32.9 ± 6.1	31.3 ± 5.4	28.6 ± 5.3	30.2 ± 5.3	28.5 ± 5.9
	Trial 2	32.0 ± 5.4	30.7 ± 5.7	28.3 ± 5.6	30.3 ± 5.3	28.0 ± 6.8
	Mean	32.5 ± 5.6 b c	31.0 ± 5.4 c	28.4 ± 5.3	30.2 ± 5.1 c	28.3 ± 6.2
	CV(%)	3.8	3.1	4.0	3.5	4.9
	TE	1.7	1.2	1.4	1.3	1.8
	r^2	0.85 a	0.92 a	0.88 a	0.88 a	0.86 a
Creatine Kinase ($U \cdot L^{-1}$)	Trial 1	240 ± 114	306 ± 91	-	443 ± 135	574 ± 227
	Trial 2	288 ± 190	382 ± 222	-	460 ± 252	568 ± 284
	Mean	264 ± 154 b	344 ± 169 b	-	451 ± 196 b	571 ± 249
	CV(%)	18.5	30.2	-	20.5	28.1
	TE	94	128	-	139	204
	r^2	0.53 a	0.36	-	0.40	0.14
Insulin ($pmol \cdot l^{-1}$)	Trial 1	170.9 ± 138.6	176.6 ± 128.3	-	137.6 ± 103.6	79.7 ± 53.8
	Trial 2	170.4 ± 131.2	175.9 ± 137.3	-	127.8 ± 102.4	75.3 ± 49.0
	Mean	170.6 ± 130.9	176.3 ± 128.9	-	132.7 ± 100.1	77.5 ± 50.0
	CV(%)	14.5	24.0	-	14.4	10.3
	TE	33.6	48.8	-	20.9	10.6
	r^2	0.88 a	0.76 a	-	0.92 a	0.92 a
NEFA ($mmol \cdot l^{-1}$)	Trial 1	0.18 ± 0.11	0.78 ± 0.53	-	1.98 ± 0.49	2.62 ± 0.72
	Trial 2	0.20 ± 0.14	1.04 ± 0.50	-	2.03 ± 0.52	2.54 ± 0.87
	Mean	0.18 ± 0.11 b	0.91 ± 0.43 b	-	2.01 ± 0.48 b	2.58 ± 0.73
	CV(%)	16.7	39.2	-	9.6	13.2
	TE	0.06	0.34	-	0.22	0.42
	r^2	0.50 a	0.28	-	0.66 c	0.53 a
Glycerol ($\mu mmol \cdot l^{-1}$)	Trial 1	21 ± 11	135 ± 54	-	300 ± 91	432 ± 157
	Trial 2	20 ± 13	162 ± 45	-	330 ± 73	460 ± 169
	Mean	21 ± 12 b	149 ± 50 b	-	315 ± 82 b	446 ± 159
	CV(%)	12.9	19.8	-	11.8	12.5
	TE	5	23	-	40	63
	r^2	0.74a	0.64 a	-	0.61 a	0.74 a
Interleukin-6 ($pg \cdot ml^{-1}$)	Trial 1	7.4 ± 16.8	12.0 ± 20.8	-	14.2 ± 22.0	10.4 ± 13.5
	Trial 2	8.1 ± 20.4	11.9 ± 17.0	-	11.4 ± 19.4	11.7 ± 19.6
	Mean	7.7 ± 18.2	12.0 ± 20.3	-	12.8 ± 20.3	11.0 ± 16.4
	CV(%)	18.5	15.8	-	6.5	24.0
	TE	2.8	3.8	-	5.2	4.7
	r^2	0.98 a	0.96 a	-	0.90 a	0.98 a

Table 5b.2 Physiological and performance data (mean ± SD). E1-E8 = 0-15, 16-30, 31-45, 46-60, 61-75, 76-90, 90-105, 106-120 min, respectively. Mean = mean values of trials 1 and 2. HR_{mean} = mean HR. RPE = rating of perceived exertion. CV = coefficient of variation (%). TE = typical error. *r* = Pearsons correlation coefficient. a = $p \leq 0.05$. b = significant difference from E8 ($p \leq 0.05$).

Variable		Timing							
		E1	E2	E3	E4	E5	E6	E7	E8
HR_{mean} (bpm)	Trial 1	158 ± 15	161 ± 14	162 ± 13	158 ± 12	161 ± 12	163 ± 11	159 ± 12	164 ± 10
	Trial 2	157 ± 11	160 ± 14	164 ± 13	155 ± 10	161 ± 13	163 ± 13	159 ± 7	162 ± 9
	Mean	158 ± 13	161 ± 14	163 ± 13	156 ± 11	161 ± 12	163 ± 11	159 ± 10	163 ± 9
	CV(%)	2.0	1.7	1.8	2.3	1.4	1.8	3.0	2.3
	TE	4.23	3.51	4.90	4.51	2.80	3.84	7.54	5.61
	r^2	0.86 a	0.88 a	0.74 a	0.74 a	0.90 a	0.81 a	0.23	0.42 a
RPE (units)	Trial 1	12 ± 2	13 ± 3	14 ± 3	13 ± 3	15 ± 3	15 ± 3	16 ± 3	17 ± 3
	Trial 2	11 ± 3	13 ± 3	13 ± 3	13 ± 3	14 ± 3	15 ± 3	16 ± 3	17 ± 3
	Mean	11 ± 3 b	13 ± 3 b	14 ± 3 b	13 ± 3 b	15 ± 3 b	15 ± 3 b	16 ± 3 b	17 ± 3
	CV(%)	7.2	5.2	6.5	6.4	6.6	4.7	3.1	2.0
	TE	0.99	0.76	0.96	1.22	1.01	0.91	0.70	0.62
	r^2	0.79 a	0.92 a	0.86 a	0.71 a	0.79 a	0.86 a	0.92 a	0.94 a
Dribble Velocity ($m \cdot s^{-1}$)	Trial 1	2.33 ± 0.20	2.34 ± 0.22	2.25 ± 0.23	2.30 ± 0.26	2.31 ± 0.22	2.28 ± 0.29	2.25 ± 0.20	2.24 ± 0.21
	Trial 2	2.28 ± 0.23	2.34 ± 0.28	2.32 ± 0.29	2.29 ± 0.26	2.35 ± 0.36	2.29 ± 0.24	2.23 ± 0.24	2.19 ± 0.25
	Mean	2.30 ± 0.21	2.34 ± 0.24	2.29 ± 0.26	2.29 ± 0.25	2.33 ± 0.29	2.29 ± 0.26	2.24 ± 0.22	2.21 ± 0.22
	CV(%)	2.8	4.0	3.3	2.9	6.0	4.9	2.6	2.8
	TE	0.09	0.13	0.08	0.08	0.20	0.15	0.08	0.08
	r^2	0.71 a	0.50 a	0.84 a	0.81 a	0.40 a	0.50 a	0.76 a	0.76 a
Dribble Success (%)	Trial 1	93 ± 7	87 ± 19	94 ± 6	95 ± 5	97 ± 4	96 ± 5	91 ± 11	91 ± 8
	Trial 2	95 ± 5	94 ± 8	96 ± 6	93 ± 6	92 ± 7	90 ± 14	93 ± 8	90 ± 9
	Mean	94 ± 6	90 ± 15	95 ± 6	94 ± 6	95 ± 6	93 ± 11	92 ± 9	90 ± 8
	CV(%)	4.0	9.0	3.4	5.3	6.7	8.0	13.3	8.2
	TE	5	13	5	6	7	10	8	9
	r^2	0.06	0.07	0.11	0.01	0.2	0.05	0.09	-0.02
Dribble Precision (cm)	Trial 1	41.5 ± 4.7	37.6 ± 10.5	42.9 ± 8.2	38.2 ± 5.3	37.3 ± 7.4	40.9 ± 8.4	38.3 ± 4.8	39.4 ± 4.6
	Trial 2	40.8 ± 6.1	37.5 ± 4.2	37.9 ± 4.9	38.6 ± 6.7	41.8 ± 4.6	38.6 ± 5.0	38.0 ± 2.4	35.6 ± 5.4
	Mean	41.2 ± 5.3	37.6 ± 7.8	40.4 ± 7.1	38.4 ± 5.9	39.6 ± 6.4	39.8 ± 6.8	38.2 ± 3.7	37.5 ± 5.3
	CV(%)	5.0	10.5	11.1	8.6	12.4	8.6	7.8	11.5
	TE	2.60	6.79	4.64	4.25	4.68	4.24	3.62	4.25
	r^2	0.64 a	0.17	0.36	0.27	0.22	0.50 a	0.01	0.09
15m Sprint Speed ($m \cdot s^{-1}$)	Trial 1	5.63 ± 0.29	5.53 ± 0.25	5.53 ± 0.27	5.48 ± 0.26	5.44 ± 0.28	5.35 ± 0.30	5.24± 0.26	5.17 ± 0.36
	Trial 2	5.62 ± 0.23	5.55 ± 0.26	5.54 ± 0.29	5.44 ± 0.16	5.47 ± 0.20	5.39 ± 0.18	5.28 ± 0.36	5.06 ± 0.43
	Mean	5.62 ± 0.26 b	5.54 ± 0.25 b	5.54 ± 0.27 b	5.46 ± 0.21 b	5.45 ± 0.24 b	5.37 ± 0.25 b	5.26 ± 0.30 b	5.12 ± 0.39
	CV(%)	1.5	1.2	1.6	1.8	1.8	2.7	3.2	4.6
	TE	0.10	0.08	0.13	0.13	0.13	0.20	0.26	0.32
	r^2	0.76 a	0.79 a	0.61 a	0.52 a	0.58 a	0.19	0.12	0.13

5b.3.2 Reliability of Physiological Responses

Blood glucose, RPE, HR_{mean}, and T_{core} demonstrated good absolute reliability (CVs ≤ 8.1%), and moderate to very strong relative reliability (r ≥ 0.48) during exercise (Figure 5b.1 and Table 5b.2). Plasma CK, insulin, NEFA, glycerol, and IL-6 had strong to very strong relationships between trials across all time points (r ≥ 0.53 – 0.99) except for 120 min CK concentrations (r = 0.38) (Table 5b.1). Absolute reliability of these variables was disparate depending on the particular time-point examined; with three quarters of CVs being ≤ 15.8% (Table 5b.1) and post-first half being the most variable time-point. Although blood lactate showed strong to very strong correlations (r ≥ 0.69), average CVs were 20% during exercise (Figure 5b.1). There were no between-trial differences ($p > 0.05$) for all performance variables and all but one of the physiological variables (blood lactate) examined over 120 min (Figure 5b.1 and Tables 5b.1 and 5b.2). Significant differences in blood lactate concentrations were observed between trials ($p = 0.005$, $\eta^2 = 0.315$) at E1 (1.6 ± 1.7 mmol·l^{-1}, $p = 0.014$), E2 (1.1 ± 0.9 mmol·l^{-1}, $p = 0.004$), E5 (1.2 ± 1.3 mmol·l^{-1}, $p = 0.014$), and E6 (1.1 ± 1.0 mmol·l^{-1}, $p = 0.007$) (Figure 5b.1).

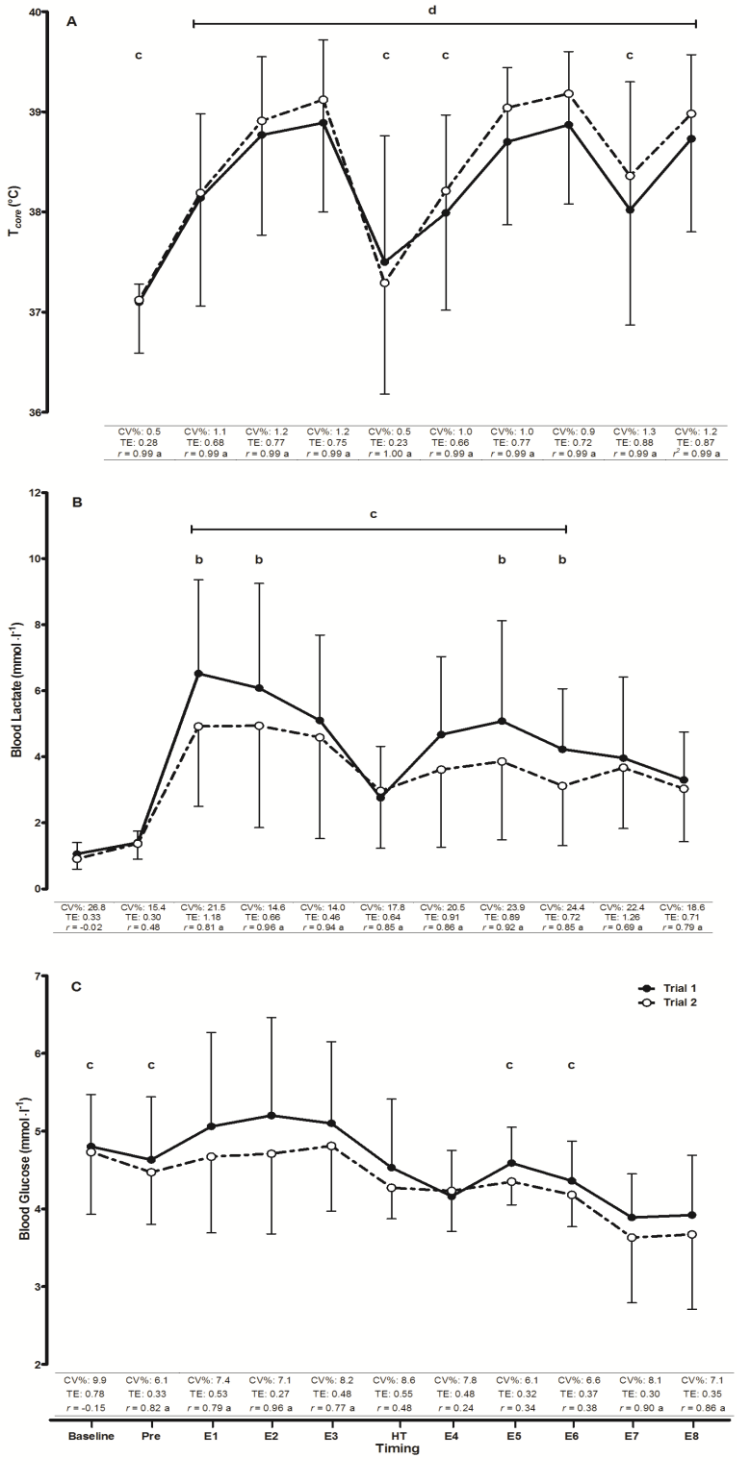

Figure 5b.1 Core Temperature (T_{core}) (A), blood lactate (B), and blood glucose (C) concentrations during trials 1 and 2. Pre = pre-exercise. E1-E8 = 0-15, 16-30, 31-45, 46-60, 61-75, 76-90, 90-105, 106-120 min, respectively. HT = half-time. CV = coefficient of variation (%). TE = typical error. *r* = Pearsons correlation coefficient. a = $p \leq 0.05$ (significant correlation). b = significant difference between trials ($p \leq 0.05$). c = significant difference from E8 ($p \leq 0.05$). d = significant difference from HT ($p \leq 0.05$).

5.b.3.3 Performance and Physiological Responses across 120 min

At 120 min, 20 m sprint speeds were reduced compared to baseline ($p = 0.013$, $d = 1.0$), and post-first half ($p = 0.042$, $d = 0.7$), and CMJ height was lower versus baseline ($p = 0.027$, $d = 0.7$) (Table 5b.1). Pre-second half, CMJ heights were lower than baseline ($p \leq 0.0005$, $d = 0.7$), post-first half ($p \leq 0.0005$, $d = 0.5$) and at 90 min ($p = 0.002$, $d = 0.3$), with 20 m sprint speeds being slower at this time when compared to baseline ($p \leq 0.0005$, $d = 0.2$) and post-first half ($p \leq 0.0005$, $d = 0.5$) (Table 5b.1). During E8, 15 m sprint speeds were reduced (−0.14 to −0.51 $m \cdot s^{-1}$), and RPE was elevated (+1-6 units), when compared to all other time-points (both $p < 0.05$, $d \leq 1.6$) (Table 5b.2). During E8, T_{core} was greater than baseline, E1, HT, E4, and E7 (all $p \leq 0.016$, $d \leq 2.3$) (Figure 5b.1) while T_{core} at HT was reduced compared to all other time-points except baseline (all $p \leq 0.019$, $d \leq 1.3$) (Figure 5b.1).

At 120 min, CK concentrations were elevated compared to baseline, post-first half and 90 min (all $p \leq 0.002$, $d \leq 1.4$; Table 5b.1). Plasma NEFA and glycerol concentrations were higher than all other time points at 120 min (all $p \leq 0.006$, $d \leq 3.2$) (Table 5b.1). Blood glucose concentrations were lower during E8 compared to baseline, pre-exercise, E3, E5, and E6 (all $p \leq 0.042$, $d \leq 1.4$) (Figure 5b.1). Similarly, blood lactate concentrations reduced during E8 compared to all other epochs (all $p \leq 0.05$, $d \leq 2.0$) except E7 (Figure 5b.1). Body mass was lower at 120 min (75.0 ± 6.8 kg) compared to baseline (77.0 ± 6.8 kg, −2.6 ± 1.4%, $p = 0.001$, $d = 0.3$), and 90 min (75.8 ± 6.8 kg, −1.0 ± 0.5%, $p \leq 0.0005$, $d = 0.1$). Urine osmolality remained unchanged from pre- (693 ± 163 $mOsmol \cdot kg^{-1}$) to post-exercise (570 ± 157 $mOsmol \cdot kg^{-1}$; $p > 0.05$).

5b.4 DISCUSSION

This is the first study to examine the reliability of performance and physiological responses to a soccer-specific protocol, specifically the SMS, over 120 min. In agreement with our hypotheses, the majority of variables yielded good test-retest reliability across the protocol duration. Furthermore, I observed perturbations in performance and physiological responses during ET. The SMS is a reliable protocol that can be used to profile exercise-induced changes in a number of variables, and can also be utilised to investigate the efficacy of interventions that may improve performance.

The absence of systematic bias between trials for measures of physical performance demonstrates good test-retest reliability and a lack of learning effects or fatigue for these parameters. Moreover, as per Atkinson and Nevill (1998), all physical performance variables yielded acceptable CVs throughout the duration of exercise (all < 10%). Notably, CVs for 15 m and 20 m sprint speeds were 4.6% and 3.5% at 120 min, respectively, with TEs of 0.32 $m \cdot s^{-1}$ and 0.25 *s*. These are comparable to previous investigations utilising match simulation protocols (Russell et al., 2011a; Sykes et al., 2013). CMJ height, HR_{mean} and RPE all had CVs of ≤ 4.9% in ET (Tables 5b.1 and 5b.2), similar to previous research using the SMS for 90 min (Russell et al., 2011a). Knowledge of this reliability data allows researchers to detect 'real' changes in the measured variables during intervention-type studies (i.e., outside the error of measurement; Sykes et al, 2013).

Although no systematic bias existed between trials for indices of technical performance (i.e., dribbling velocity, precision and success), absolute reliability varied across exercise (2.8 to 13.3%; Table 5b.2). In ET, dribble velocity demonstrated low CVs (2.6-2.8%), a small TE (0.08 $m \cdot s^{-1}$) and strong correlation (r = 0.87) (Table 5b.2). Dribble precision and success had CVs of 7.8-13.3% and weak correlations (r ≤ 0.30) in ET (Table 5b.2). Both physical and mental fatigue influences skill performance (Rampinini et al., 2009; Smith et al., 2015), and measures of skill typically demonstrate high variability (Russell et al., 2010). A previous investigation using the SMS observed lower CVs for the dribbling variables measured (Russell et al., 2010); however, skill performance was conducted in a non-fatigued state (i.e., no prior exercise) by a mix of

professional and university-standard players. Therefore, the greater variation in dribble precision and success observed in the present study is possibly due to the level of player and/or greater fatigue during ET.

There was no systematic bias between trials for the measured physiological variables except blood lactate. Core temperature demonstrated excellent reliability with CVs of ≤ 1.3% and near perfect correlation between trials (r ≥ 0.99) (Figure 5b.1). Blood glucose showed good reliability in ET with CVs of ≤ 8.1% and r values of ≥ 0.86 (Figure 5b.1). To my knowledge this is the first study to assess the reliability of measures of blood glucose concentrations during a soccer-specific protocol. The consistency of the blood glucose response supports the use of this variable, amongst others, to investigate the efficacy of carbohydrate ingestion in exercising soccer players (Kingsley et al., 2014). Although the pattern of response for insulin, IL-6, NEFA and glycerol were similar between trials (r = 0.96, 0.99, 0.73, and 0.86, respectively), due to the inherent variability associated with blood parameters (Meister et al., 2014), the CVs were ≥ 10.3% (Table 5b.1). CK was the most variable measure, however; this was expected due to large inter-individual differences, the cause of which is generally unknown (Heled et al., 2007).

There was systematic bias between trials for blood lactate, with differences at some specific time points (Figure 5b.1). Although trials were standardised, small variations in prior activity can cause fluctuations in blood lactate concentrations (Russell & Kingsley, 2012), and may explain this isolated discrepancy. As no differences were found for performance measures between trials, or for resting and pre-exercise values, I believe differences in blood lactate do not reflect a lack of recovery between trial days. However, readers should exercise caution when interpreting blood lactate responses from investigations using the SMS.

Although > 20 participants are recommended for reliability studies, recruitment of this magnitude is difficult due to the challenging, time-consuming nature of the protocol while maintaining a homogenous population. As has been utilised previously (Sirotic & Coutts, 2008; Aldous et al., 2014) I consulted Batterham and Atkinson's nomogram using my calculated CVs and found a sample size of 10 is sufficient to detect a 5-10% difference in 20 m sprint speed, CMJ height, and dribble and 15-m sprint velocities during ET (Batterham & Atkinson, 2005).

As sprinting is the most frequent action associated with goal scoring in soccer (Faude et al., 2012), and dribbling is an important factor in match success (Zago et al., 2015), these are important variables to note. However, I acknowledge the high CVs at some time-points for certain metabolic variables (Table 5b.1). Therefore, readers should be cognisant of these values when interpreting changes in in the aforementioned variables at these time-points (Gregson et al., 2010).

I observed reduced 15 m sprint speeds during the last 15 min of ET, and reductions in 20 m sprint speed at 120 min. These findings agree with a case study that observed reductions in high-intensity distance covered in ET compared to the prior 90 min during a competitive soccer match (Russell et al., 2015). Although there were elevations in T_{core} during E8, average T_{core} was 38.9 ± 1.0°C, over 1°C lower than what the American College of Sports Medicine consider exertional hyperthermia (40°C; ACSM, 2007). However, as the current study was conducted in a temperate environment (19.7°C), implications for T_{core} and performance during ET periods played in hot conditions might exist. Certain aspects of soccer performance and T_{core} are negatively impacted during 90 min matches played in the heat (Mohr et al., 2012) and there seems to be a climate-dependent modulation of performance by soccer players (Nassis et al., 2015). Therefore, the possible health risks and repercussions for performance during ET in hot climates require investigation.

I observed further reductions in body mass during ET, with a 0.7 ± 0.4 kg drop at 120 min compared to at 90 min, which may be indicative of further dehydration in ET. However, there were no changes in urine osmolality in the present investigation. Furthermore, I observed significant reductions in blood glucose in ET, with 50% of participants exhibiting concentrations considered hypoglycaemic (< 3.6 $mmol \cdot l^{-1}$ (Figure 5b.1; Cryer et al., 2003). Investigations into the efficacy of carbohydrate feeding during 120 min of simulated match-play are required.

In concordance with chapter 5a I observed reduced blood glucose and lactate concentrations with concomitant elevations in plasma NEFA and glycerol concentrations during ET, implying an increased rate of lipolysis and a decreased rate of substrate level phosphorylation. As maintenance of

intermittent exercise capacity is dependent upon glycogenolysis (Mohr & Krustrup, 2005), greater fat oxidation during ET may explain the reductions in sprint performance observed. I detected CK concentrations at 120 min of 571 ± 249 $U \cdot L^{-1}$, similar to those observed following a competitive match that required ET (586.6 $U \cdot L^{-1}$; Russell et al., 2015). Consequently, ET may have repercussions with regards to muscle damage and recovery, especially as matches that require ET tend to be in close proximity (72 h) to other matches.

I acknowledge a certain lack of individualization of the protocol compared to existing non-motorised treadmill based protocols (Aldous et al., 2014); however, the movement patterns of the SMS are designed to simulate match-play as opposed to providing a test of performance *per se*. As performance measures are frequently taken during the protocol (15 m and 20 m sprint speeds, and dribbling and CMJ performance) these provide a quantitative examination of fatigue responses across 120 min of simulated match-play that are controlled by the individual.

Furthermore, assessing the influence of the environment on performance during ET using the SMS would require the protocol to be performed outdoors where conditions can vary or in a climate-controlled hall or dome. As the use of environmental chambers allows better control of conditions, utilising valid and reliable treadmill-based protocols may be more apposite to investigate the effect of heat or altitude (Coull et al., 2015). However, there is scope for incorporating skill actions into treadmill-based protocols.

5b.5 CONCLUSIONS

The SMS was found to be a reliable protocol for measuring responses to 120 min of soccer-specific exercise, utilising a high time resolution approach to profile the reliability of responses. ET compromises performance and causes physiological perturbations that have acute and possibly chronic implications (i.e., in- and post-match). Researchers can use the SMS to reliably provide an intermittent exercise stimulus over 120 min and thus evaluate the efficacy of intervention strategies and the profiling of fatigue responses. Furthermore, coaches and practitioners responsible for the preparation and recovery of soccer players should be cognisant of the deleterious effects of ET compared to 90 min.

6a.0

PHYSIOLOGICAL AND PERFORMANCE EFFECTS OF CARBOHYDRATE GELS CONSUMED PRIOR TO THE EXTRA-TIME PERIOD OF PROLONGED SIMULATED SOCCER MATCH-PLAY

This work has been published in a peer reviewed journal:

Harper LD, Briggs MA, McNamee G, West DJ, Kilduff LP, Stevenson E, Russell M. Physiological and performance effects of carbohydrate gels consumed prior to the extra-time period of prolonged simulated soccer match-play. J Sci Med Sport 2016, 19(6), 509-514.

Chapter Summary

- The practitioners surveyed in chapter 3 identified nutritional interventions as the most important future research area.
- Deleterious effects on performance and physiology have been observed in chapters 4, 5a, and 5b and so the influence of a nutritional intervention during extra-time presents itself as a research opportunity.
- In this investigation eight English Premier League academy soccer players performed 120 min of the Soccer Match Simulation on two occasions .Carbohydrate-electrolyte (0.7 ± 0.1 $g \cdot kg^{-1}$ BM) or energy-free placebo gels were consumed ~5 min before extra-time in a randomised, double-blind, crossover design
- Carbohydrate-electrolyte gel ingestion raised blood glucose concentrations and improved dribbling performance during the extra-time period of simulated soccer match-play. Supplementation did not attenuate reductions in physical performance and hydration status that occurred during extra-time

6a.1 INTRODUCTION

When scores are tied at the end of specific soccer tournament matches, a 30 min extra-time (ET) period is played. According to official match data (www.FIFA.com), 22% and 35% of knockout phase matches played between 2002 and 2014 at U17 and senior FIFA World Cup competitions required ET, respectively. Given the importance of ET in soccer tournaments, the dearth of literature profiling, 1) the demands of this additional period of play, and 2) the effects of ergogenic interventions throughout 120 min of soccer-specific exercise, is surprising.

Reductions in performance capacity have been observed following intense periods of competition (Mohr et al., 2003) after a passive half-time period (Lovell et al., 2013), and during simulated and actual soccer match-play (Bradley et al., 2009; Russell et al., 2012). Although a topic of debate (Mohr et al., 2005; Reilly et al., 2008; Russell & Kingsley, 2012), the mechanisms of reduced performance have primarily been attributed to physiological responses that are either central (i.e., central nervous system; Mohr et al., 2005) or peripheral (i.e., disturbances in acid-base balance, blood glucose concentrations, muscle ion homeostasis, hydration status, muscle temperature and/or fibre-specific glycogen content) in origin (Mohr et al., 2005; Bendiksen et al., 2012; Russell & Kingsley, 2012).

Ergogenic effects have been observed following provision of carbohydrates on physical and skilled actions performed throughout simulated soccer match-play (Ali et al., 2007; Russell et al., 2012; Kingsley et al., 2012). Increased exogenous energy provision, maintenance of blood glucose concentrations, and improved intermittent exercise capacity has been reported following carbohydrate gel ingestion (Patterson & Gray, 2007; Havemann & Goedecke, 2008; Kingsley et al., 2014). Although the ingestion of carbohydrate gels prior to ET is common in professional soccer, the physiological and performance responses to this nutritional strategy are unknown.

Therefore, the aim of this study was to evaluate the physiological and performance responses to carbohydrate-electrolyte gels consumed before the ET period of a simulated soccer match. I hypothesised that carbohydrate provision would influence physiological and performance responses during ET.

6a.2 METHODS

This study received ethical approval from the Health and Life Sciences Ethics Committee at Northumbria University. Male soccer players recruited from an English Premier League club (n = 8, age: 16 ± 1 years, mass: 68.5 ± 5.3 kg, stature: 1.73 ± 0.05 m, estimated $\dot{V}O_{2\ max}$: 55 ± 9 $ml \cdot kg^{-1} \cdot min^{-1}$) provided written informed consent (and parental consent where players <18 years). Players trained for ~16 hours per week and played for a professional academy for >12 months before the study started. Two main trials (carbohydrate: CHO and placebo: PLA), separated by 9 ± 4 days, were completed using a double-blind, randomised, counterbalanced and cross-over design.

A preliminary visit included estimation of $\dot{V}O_{2\ max}$ (Bangsbo et al., 2008) and procedural habituation, with main trials performed on two subsequent visits. Players performed a light 45 min training session (involving positional and tactic-specific drills), refrained from caffeine consumption and recorded all food consumed (analysed retrospectively; Nutritics Ltd., UK) in the 24 h preceding each main trial. Following an overnight fast, players arrived at 08:00 h and provided a mid-flow urine sample. A resting fingertip capillary blood sample was taken before players consumed a standardised breakfast (2079 kJ, 77.1 g carbohydrates, 12.3 g fats, and 14.3 g proteins) including 500 ml of a fluid-electrolyte beverage (Mineral Water, Highland Spring, UK). Body mass and stature (Seca GmbH & Co., Germany) were then measured.

A pre-exercise blood sample was taken after players rested for ~90 min following breakfast. A standardised warm-up (including multidirectional and linear speed drills, dynamic stretching and dribbling practice), during which players consumed 200 ml of the fluid-electrolyte beverage, was then performed. Performance testing (PT) preceded exercise, with countermovement jump (CMJ) height (Lopez-Segovia et al., 2015) and 30 m repeated sprint maintenance (RSM; Glaister et al., 2008) were assessed. Players performed three CMJ's interspersed with 10 s passive recovery and three 30 m sprints with 25 s of active recovery. These assessments were repeated on a further four occasions (i.e., post-first half; P2, pre-second half; P3, post-second half; P4, post-exercise; P5).

Using a modified version of the Soccer Match Simulation (SMS; Russell et al., 2011b) participants performed 120 min of soccer-specific exercise; consisting of two 45 min halves and two additional 15 min periods (ET). The repeatability of the physiological and performance responses to the original SMS have been determined (Russell et al., 2011a). Directed by audio signals, the SMS required players to cover ~14.4 km (reflecting actual match-play requiring ET; Russell et al., 2015b) at various running intensities, with backwards and sideward movements over a 20-m distance, while intermittently performing 15 m sprints and 18 m ball dribbles (assessed for precision, percentage success, and average speed; Russell et al., 2012) Dribbling performance was expressed as an average per 15 min of exercise (epochs; E*N*): 0-15 min (E1), 16-30 min (E2), 31-45 min (E3), 46-60 min (E4), 61-75 min (E5), 76-90 min (E6), 91-105 min (E7) and 106-120 min (E8).

A 15 min half-time (HT) passive recovery period, where players consumed 500 ml of a fluid-electrolyte beverage, separated the two 45 min halves. Five min of rest followed the end of normal time and a two min period separated each half of ET. Body mass assessment and gel consumption (with 300 ml of fluid-electrolyte beverage) preceded the start of ET. Gels were professionally manufactured and were taste and texture matched (IsoGel, High5 Ltd., UK). Sachets providing 0.7 ± 0.1 $g \cdot kg^{-1}$ BM carbohydrates derived from glucose and maltodextrin (808 kJ; 46 g carbohydrates, 0 g fats, 0 g proteins, 0.14 g salt; CHO) or placebo (0 kJ; 0 g carbohydrates, fats and proteins 0.14 g salt; PLA) were consumed using a double-blind, randomised and counterbalanced design.

Fingertip capillary blood samples (170 µl) were collected at rest, P1, HT and at the end of each epoch (i.e., E1-E8) and analysed for blood glucose, lactate and sodium concentrations (GEM Premier 3000; Instrumentation Laboratory, UK; CV's: 0.6-2.2%; Benetaeu-Burnat et al., 2004). Urine and plasma osmolality (Advanced Model 3300 Micro-Osmometer; Advanced Instruments Inc., USA), urine-corrected mass changes, ratings of perceived exertion (RPE; Borg, 1982; Appendix 3) and abdominal discomfort (AD; similar to the methods of Rowlands et al., 2008; Appendix 4) were recorded during each trial. Environmental conditions were measured during exercise (Technoline WS-9032; Technotrade

GmbH, Germany) and heart rate (HR) was recorded (Polar RS400; Polar Electro, Finland). A mid-flow urine sample was collected post-exercise and body mass was measured.

Statistical analyses were carried out using SPSS Statistics software (IBM Inc., USA) with significance set at $p \leq 0.05$. Data are reported as mean ± standard deviation (SD). Statistical power was calculated using commercially available software (GPower v3.1, Germany) and a sample size of eight was deemed sufficient for >80% power to detect statistical differences in blood glucose and dribbling precision. For parametric data (confirmed by normality and variance assessments), paired sample t-tests were performed for single time-point data. For parametric data expressed over multiple time-points, two-way repeated measures analysis of variance (within-participant factors: treatment x time) were performed. Where significant interactions were observed, supplementation was deemed to have influenced responses and simple main effects were performed. Partial eta-squared (η^2) values were calculated and LSD corrected *post-hoc* tests (with 95% Confidence Intervals; CI) with Cohen's *d* calculations examined between-trial differences. Non-parametric data were analysed using a Friedman test with *post-hoc* Wilcoxon Signed Ranks tests (ES calculated using the Z distribution value) to identify effects (Fritz et al., 2012). For η^2 and ES data, thresholds of 0.2, 0.5, and 0.8 were considered small, medium and large, respectively (Fritz et al., 2012).

6a.3 RESULTS

Ambient temperature (18.5 ± 1.5°C), humidity (74 ± 7%) and barometric pressure (1017 ± 3 mmHg) were similar between trials ($p > 0.05$). Players reported to each trial in a similar hydration state (plasma osmolality: 312 ± 6 $mOsmol \cdot kg^{-1}$, $p = 0.936$). Energy intake (8.6 ± 0.7 $MJ \cdot d^{-1}$) and macronutrient content (carbohydrate, fats, proteins: 3.7 ± 0.4, 2.7 ± 0.8, 2.2 ± 0.3 $MJ \cdot d^{-1}$, respectively) was similar across trials ($p > 0.05$).

Supplementation influenced mean dribbling precision ($p = 0.015$, $\eta^2 = 0.287$) with dribbles performed during E8 being 29 ± 20% more accurate in CHO than PLA ($p = 0.014$, $d = 1.3$, CI: 3.24-21.01 cm; Figure 6a.1A). Dribbles were also more accurate during E5 in CHO than PLA ($p = 0.002$, $d = 1.0$, CI: 3.8-11.3 cm; Figure 6a.1A). Although dribbling speed ($p = 0.671$, $\eta^2 = 0.091$) and success ($p = 0.677$, $\eta^2 = 0.070$) were not affected by supplementation (Figure 6a.1B and 6a.1C), dribbling speed was lower ($p < 0.001$, $\eta^2 = 0.500$) during E7 and E8 compared to E1 (-12.3 ± 3.8%, -10.1 ± 6.6%, respectively, both $p < 0.001$) (Figure 6a.1B). Dribbles in E8 were 4.6 ± 5.9% slower than E6 ($p = 0.046$) and 5.7 ± 4.7% slower during E6 versus E1 ($p = 0.012$) (Figure 6a.1B).

Supplementation did not influence 15 or 30 m sprint velocities ($p = 0.772$, $\eta^2 = 0.044$ and $p = 0.599$, $\eta^2 = 0.091$, respectively). Likewise, 30 m RSM and CMJ height were similar between trials ($p = 0.528$, $\eta^2 = 0.104$ and $F_{(4,28)} = 1.072$, $p = 0.389$, $\eta^2 = 0.133$, respectively). However, exercise influenced these variables ($p < 0.001$, $\eta^2 = 0.640$; $F_{(7,49)} = 7.026$, $p < 0.001$, $\eta^2 = 0.501$; $p < 0.001$, $\eta^2 = 0.527$ and $p = 0.053$, $\eta^2 = 0.370$, respectively). Sprint velocities over 15 m reduced during E7 (5.52 ± 0.57 $m \cdot s^{-1}$) and E8 (5.37 ± 0.56 $m \cdot s^{-1}$) when compared to E1 (5.92 ± 0.47 $m \cdot s^{-1}$) (both $p < 0.01$) and during E8 compared to E6 (5.63 ± 0.58 $m \cdot s^{-1}$) ($p = 0.001$). Sprint velocities over 30 m (-4 ± 2%, $p = 0.003$) and RSM scores (-4 ± 3%, $p = 0.003$) were lower at P5 versus P1 (Table 6a.1). Decrements between E6 and E1 existed for 15 m sprint velocities (-5 ± 4%, $p = 0.010$) and between P4 and P1 for 30 m sprint velocities (-3 ± 3%, $p = 0.036$) and 30 m RSM (-3 ± 3%, $p = 0.018$) (Table 6a.1). Compared to other time-points, CMJ height was not different at P5, however; CMJ height, 30 m sprint velocities and 30 m RSM were dampened at P3 compared to both P1 (-7 ± 4, -4

± 2, -5 ± 3%, respectively, all $p < 0.05$) and P2 (-5 ± 4, -3 ± 3, -3 ± 3%, respectively, all $p < 0.05$) (Table 6a.1).

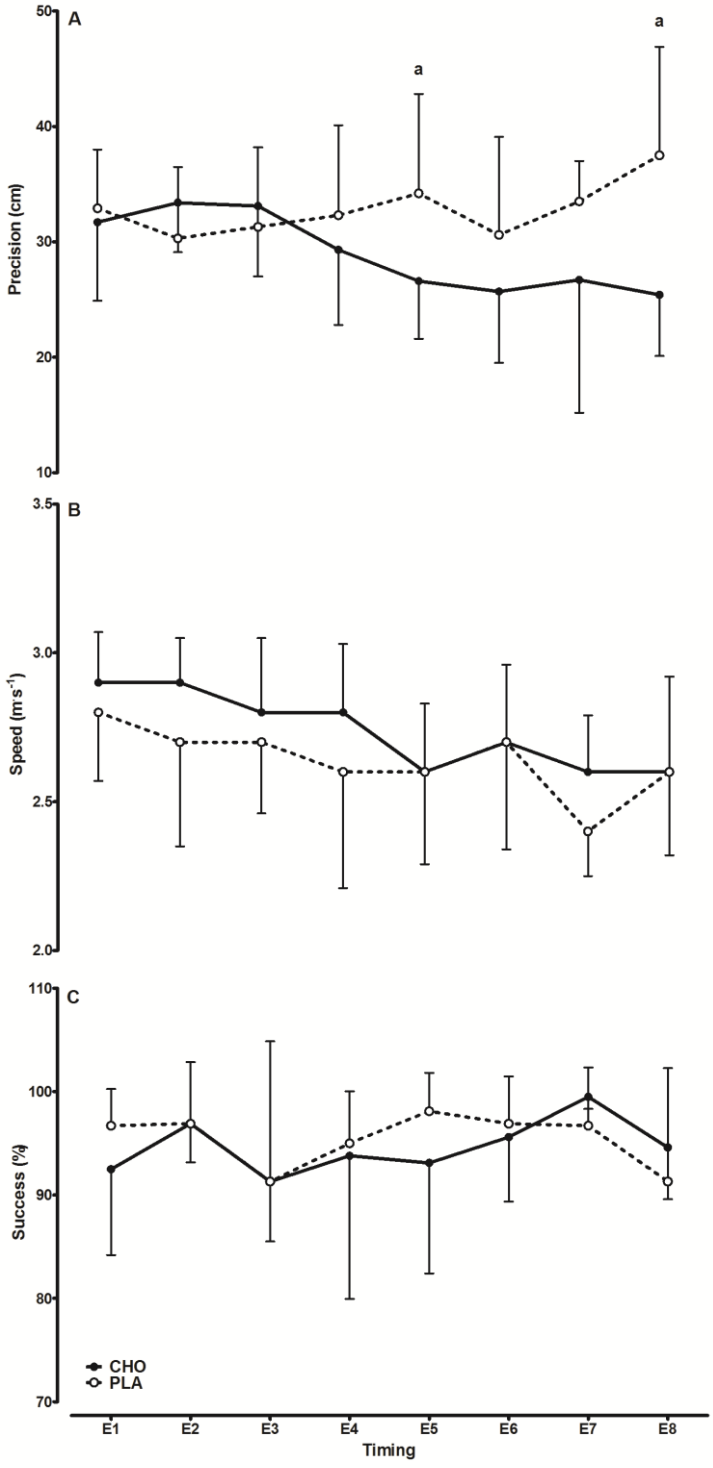

Figure 6a.1 Dribbling precision (A), speed (B) and success (C) throughout each trial (mean ± SD). E1-8 represents 0-15, 16-30, 31-45, 46-60, 61-75, 76-90, 91-105 and 106-120 min respectively and HT represents half-time. a = significant difference between CHO and PLA ($p < 0.05$) at corresponding time-point.

Table 6a.1 Performance variables as a function of timing and trial

Variable	Trial	Timing				
		P1	P2	P3	P4	P5
30-m Sprint Velocities ($m \cdot s^{-1}$)	CHO	6.95 ± 0.25	6.80 ± 0.23	6.61 ± 0.33	6.70 ± 0.31	6.76 ± 0.19
	PLA	6.97 ± 0.31	6.92 ± 0.16	6.72 ± 0.30	6.83 ± 0.34	6.63 ± 0.51
30-m Repeated Sprint Maintenance (%)	CHO	99 ± 1	96 ± 4	93 ± 6	95 ± 4	96 ± 3
	PLA	98 ± 1	98 ± 2	94 ± 5	96 ± 4	93 ± 7
CMJ Height (cm)	CHO	34.5 ± 3.2	33.9 ± 2.8	32.3 ± 3.2	33.5 ± 2.5	33.8 ± 2.5
	PLA	35.5 ± 3.7	35.2 ± 4.4	33.2 ± 3.9	35.6 ± 5.0	33.8 ± 6.2

P1-5 represents pre-exercise, post-first half, pre-second half, post-second half and post-exercise, respectively. CMJ = countermovement jump. CHO = carbohydrate gel trial, PLA = placebo gel trial. Data presented as mean ± SD.

Supplementation did not influence RPE ($p = 0.623$, $\eta^2 = 0.098$), however; timing effects were present ($p < 0.001$, $\eta^2 = 0.858$), with significantly higher RPE values during E7 (15 ± 3) and E8 (17 ± 3) compared to E1 (11 ± 3) and E6 (14 ± 3) (all $p < 0.01$). Similarly, increases were found in RPE during E6 versus E1 ($p < 0.001$). The pattern of response for mean HR (HR_{mean}) was not influenced by supplementation ($p = 0.852$, $\eta^2 = 0.023$) or exercise ($p = 0.086$, $\eta^2 = 0.297$).

Table 6a.2 Blood metabolite data as a function of timing and trial

Variable	Trial	Timing										
		Rest	**Pre**	**E1**	**E2**	**E3**	**HT**	**E4**	**E5**	**E6**	**E7**	**E8**
Glucose ($mmol \cdot l^{-1}$)	CHO	5.0 ± 0.6	5.7 ± 0.6	5.1 ± 0.5	4.7 ± 0.5	4.8 ± 0.4	4.5 ± 0.6	4.3 ± 0.4	4.3 ± 0.2	4.5 ± 0.5	5.6 ± 0.9[a]	5.0 ± 0.6
	PLA	4.9 ± 0.3	5.7 ± 0.5	4.9 ± 0.3	4.7 ± 0.3	4.7 ± 0.3	4.8 ± 0.4	4.6 ± 0.2	4.6 ± 0.4	4.5 ± 0.4	4.6 ± 0.2	4.7 ± 0.5
Lactate ($mmol \cdot l^{-1}$)	CHO	0.8 ± 0.2	1.4 ± 0.5	5.1 ± 3.1	3.7 ± 3.6	4.8 ± 3.3	3.0 ± 1.1	3.9 ± 3.3	4.0 ± 2.7	3.4 ± 2.7	2.4 ± 1.8	2.9 ± 2.2
	PLA	0.7 ± 0.2	1.6 ± 0.7	3.4 ± 1.6	3.0 ± 1.2	3.1 ± 1.7	2.4 ± 0.5	2.4 ± 0.7	2.3 ± 0.7	2.4 ± 1.0	2.2 ± 0.7	3.3 ± 2.2
Sodium ($mmol \cdot l^{-1}$)	CHO	138 ± 2	139 ± 1	141 ± 0	142 ± 1	143 ± 2	142 ± 2	142 ± 1	143 ± 1	142 ± 4	142 ± 1	143 ± 3
	PLA	139 ± 1	140 ± 1	141 ± 1	143 ± 1	143 ± 2	141 ± 2	140 ± 2	141 ± 1	143 ± 3	142 ± 1	144 ± 3

Pre represents pre-exercise and E1-8 represents 0-15, 16-30, 31-45, 46-60, 61-75, 76-90, 91-105 and 106-120 min respectively. HT represents half-time. CHO = carbohydrate gel trial, PLA = placebo gel trial. a = significant difference between trials ($p < 0.05$). Data presented as mean ± SD.

Both supplementation ($p = 0.026$, $\eta^2 = 0.354$) and exercise ($p < 0.001$, $\eta^2 = 0.656$) influenced blood glucose concentrations with CHO values being 16 ± 17% greater than PLA during E7 (5.6 ± 0.9 mmol·l^{-1} vs. 4.6 ± 0.2 mmol·l^{-1}, $p = 0.028$, $d = 4.2$, CI: 0.18-1.93 mmol·l^{-1}) (Table 6a.2). Supplementation did not affect blood lactate or sodium concentrations ($p = 0.188$, $\eta^2 = 0.208$ and $p = 0.282$, $\eta^2 = 0.162$, respectively) but exercise did ($p = 0.006$, $\eta^2 = 0.500$, and $p < 0.001$, $\eta^2 = 0.583$, respectively) (Table 6a.2). During E7, blood lactate concentrations were lower than E1 (-94 ± 57%, $p = 0.004$) and E6 (-25 ± 25%, $p = 0.048$). Blood lactate was also lower during E6 versus E1 (-32 ± 17%, $p = 0.001$) (Table 6a.2). Blood sodium concentrations were 1.6 ± 1.9% higher during E8 compared to E1 ($p = 0.045$) and 1.0 ± 0.7% higher during E7 compared to E1 ($p = 0.005$) (Table 6a.2). Blood sodium concentrations were similar at E6 and E1 ($p > 0.05$) (Table 6a.2).

Urine osmolality was similar between treatments ($p = 0.716$, $\eta^2 = 0.020$) remaining unchanged from pre- to post-exercise in both trials (-10 ± 37%, $p = 0.391$). Supplementation did not affect plasma osmolality ($p = 0.936$, $\eta^2 = 0.001$) or body mass ($p = 0.913$, $\eta^2 = 0.003$); however, post-exercise plasma osmolality was 7 ± 4% greater ($p < 0.001$, $\eta^2 = 0.882$) than pre-exercise (332 ± 8 vs. 312 ± 6 mOsmol·kg^{-1}, $p < 0.001$). Post-exercise body mass (67.8 ± 4.7 kg) was reduced ($p < 0.001$, $\eta^2 = 0.921$) compared to resting (69.4 ± 5.0 kg; $p < 0.001$) and P4 values (68.2 ± 4.8 kg; $p = 0.001$). Supplementation did not affect AD ($p > 0.05$), but exercise did ($p < 0.001$); with E8 (5 ± 3) and E7 (5 ± 3) values being greater than E1 (2 ± 1) ($p < 0.05$, $r = 0.8$ for both). During E6, AD was higher compared to E1 ($p = 0.024$, $r = 0.8$).

6a.4 DISCUSSION

This is the first study to examine the physiological and performance effects of carbohydrate-electrolyte gels consumed prior to the ET period in soccer. In agreement with my hypotheses, increased blood glucose concentrations and improved dribbling precision occurred during ET in CHO. Additionally, we observed reductions in physical performance throughout 120 min of soccer-specific exercise with evidence highlighting further performance reductions during ET compared to the end of normal time. Therefore, consumption of carbohydrate-electrolyte gels offers an ergogenic strategy for players preparing to engage in an ET period, however; not all performance decrements were ameliorated by carbohydrate provision.

Improved skill performance (i.e., shot velocity and success) has been observed following carbohydrate ingestion (Ali et al., 2007a; Russell et al., 2012). However, the efficacy of carbohydrate provision is unknown when 120 min of soccer-specific exercise is performed. In eight professional academy soccer players, a 0.7 ± 0.1 $g \cdot kg^{-1}$ BM dose of carbohydrate raised blood glucose concentrations by 16 ± 17% (large effect; *d* = 4.2; Table 6a.2) and resulted in a 29 ± 20% improvement (large effect; *d* = 1.3; Figure 6a.1A) in dribbling precision throughout E8. Although I found an unexplainable difference prior to carbohydrate ingestion (Figure 6a.1A), improved performance of sports skills following carbohydrate consumption has previously been associated with enhanced cerebral glucose supply and preserved central nervous system integrity (Duell & Kuschinsky, 2001; Nybo, 2003) even when participants remain euglycaemic (Russell et al., 2012). Additionally, elevated blood glucose concentrations induce muscle glycogen sparing (Havemann & Goedecke, 2008), augmented neuromuscular function (Nybo, 2003) attenuated central fatigue *via* serotonergic neurotransmitter release (Ali et al., 2007a) and modified motor output resulting from stimulation of afferent brain signals *via* oropharyngeal receptor activation (Chambers et al., 2009). Although the precise mechanisms of skill performance regulation have yet to be delineated and are likely multifaceted in origin, the data expands the findings of previous studies that have observed enhanced skill performance with carbohydrate supplementation (Ali et al., 2007a; Russell et al., 2012) by demonstrating ergogenic effects of carbohydrate ingested prior to ET on dribbling precision.

Ostensibly, additional fatigue occurs throughout ET as further diminutions in performance were observed after 90 min (Table 6a.1). This finding is corroborated by observations that further reductions in high-intensity distance covered and accelerations occur throughout ET (Russell et al., 2015b). Moreover, concomitant increases in RPE, a subjective marker of exercise intensity, occurred after 90 min. Notably, the supplementation strategy used in this study did not attenuate the physical performance decrements observed throughout 120 min of soccer-specific exercise. Future research opportunities therefore exist to optimise the hydro-nutritional strategies of players competing in matches requiring ET. In agreement with previous authors (Russell et al., 2015a; Russell et al., 2015c), I observed deleterious effects of a passive HT recovery period on CMJ height, 30-m sprint velocities and RSM (Table 5a.1). Therefore, the efficacy of intervention strategies administered over HT also warrants further investigation (Russell et al., 2015c).

Temporal match-related fatigue development is a complex phenomenon, with a multitude of putative factors (Mohr et al., 2005), including depletion of endogenous fuel stores (Bendiksen et al., 2012), compromised excitation-contraction coupling (Mohr et al., 2005) and dehydration (Laitano et al., 2014). Logistical constraints prevented the assessment of each of these factors in isolation in the current investigation. Nevertheless, the timings of fluid and treatment ingestion were reflective of the hydro-nutritional practices of professional players (Laitano et al., 2014). In ambient conditions, a 1.6 ± 0.6% BM loss at P4 indicates that provision of a fluid-electrolyte beverage with breakfast, during the warm-up and at HT was sufficient to prevent reductions in mass losses that exceed 2%; a threshold commonly associated with onset of reduced performance (Laitano et al., 2014). However, ET elicited a further 0.5 ± 0.3 kg mass loss as well as increases in plasma osmolality and blood sodium concentrations (Table 5a.2); possibly indicating compromised hydration status. This may be partly due to slower gastric emptying and/or intestinal absorption, as highlighted by elevated abdominal discomfort scores during ET compared to the first 90 min of exercise (Kingsley et al., 2014). Such changes are likely components of a milieu of factors contributing to match-related fatigue and highlight the need for further research to optimise the hydro-nutritional strategies of players involved in 120 min of soccer-specific exercise.

6a.5 CONCLUSIONS

Providing carbohydrate gel (0.7 ± 0.1 $g \cdot kg^{-1}$ BM) before ET increased blood glucose concentrations and improved dribbling precision thereafter but this intervention did not appear to benefit physical performance indices which reduced throughout 120 min of exercise. Alterations in dribbling performance can influence the outcome a match (Stone & Oliver, 2009), highlighting the potential benefits of carbohydrate provision prior to ET. Moreover, ET caused additional perturbations in physical and physiological responses compared to the previous 90 min. Therefore, given the role of ET in determining tournament progression, further work is needed to develop intervention strategies that attempt to preserve physical performances throughout 120 min of soccer-specific exercise.

6b.0

THE EFFECTS OF 120 MINUTES OF SIMULATED MATCH PLAY ON INDICES OF ACID-BASE BALANCE IN PROFESSIONAL ACADEMY SOCCER PLAYERS

This work has been published in a peer reviewed journal:

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Chapter Summary

- This study investigated changes in indices of acid-base balance during 120 minutes of simulated soccer match-play that included a 30 min ET period.
- Data was collected during the placebo arm of chapter 6a. Blood lactate, pH, base excess and bicarbonate concentrations were analysed prior to exercise and every 15 min during exercise.
- Sprint speeds over 15 m reduced in ET compared to the first but not the second half. At 105 min, blood lactate concentrations reduced compared to the opening 30 min. Blood pH, base excess and bicarbonate concentrations were depressed at 120 min compared to 105 min, baseline and half-time.
- Although the perturbations in acid-base balance during ET were statistically significant, the decreases in blood pH, lactate, base excess, and bicarbonate concentrations may not represent metabolic acidosis or impairments in buffering capacity that are likely to explain reduced physical performance.

6b.1 INTRODUCTION

Soccer is a high-intensity intermittent team sport with matches typically played for 90 minutes (min). However, in certain cup and tournament scenarios (e.g., FIFA World Cup, UEFA European Championships, and Lamar Hunt U.S. Open Cup) an additional 30 min period of play (termed extra-time; ET) is necessary when an outright winner is required. Of the 16 knockout phase matches played at both the senior and U20 World Cup competitions in 2014 and 2015, 50% necessitated ET. Furthermore, 32% of senior World Cup knockout matches have required ET in competitions played since 1986 (www.FIFA.com). Compared to studies reporting responses to 90 min of soccer-specific exercise (Bangsbo et al., 2007; Reilly et al., 2008; Paul et al., 2015), relatively few have investigated the demands of ET (chapters 4-6a; Lago-Penas et al., 2015; Russell et al., 2015b).

Findings from this thesis and other investigations have indicated differential effects of ET when compared to the opening and closing periods of the normal duration of soccer match-play (chapters 4a-6a; Lago-Penas et al., 2015; Russell et al., 2015). Specifically, indices of technical (i.e., number of passes and dribbles), and physical (i.e., 15 m and 20 m sprint times) performance are reduced during ET. However, the precise mechanisms underpinning these decrements in performance have yet to be demarcated. Perturbations in acid-base balance have been implicated in soccer-specific fatigue responses during 90 min of both simulated (Russell & Kingsley, 2012) and actual match-play (Krustrup et al., 2006. Indeed, Russell and Kingsley (2012) reported a reduction in blood pH and altered buffering capacity throughout 90 min of simulated soccer-specific exercise in English Championship academy level soccer players.

Traditionally, metabolic acidosis has been associated with a multitude of fatiguing processes including the impairment of metabolic enzyme activity (Fitts, 1994), diminished excitation-contraction coupling (Allen et al., 2008), and amplified K^+ efflux from the exercising musculature (Nielsen et al., 2004). However, the role of acidosis in fatigue remains a debated topic (Westerblad et al., 2002; Cairns, 2006; Debold, 2012). Nevertheless, due to the high-intensity nature of team sport exercise, preventing acidosis is considered important

(Rampinini et al., 2010; Russell & Kingsley, 2012). Furthermore, endogenous bicarbonate concentrations, and therefore the ability to buffer metabolic by-products produced as a consequence of high-intensity intermittent exercise, may be compromised during 90 min of simulated soccer match-play (Russell et al., 2012). However, comparable data during ET has yet to be reported.

In summary, changes in acid-base balance have been postulated to contribute to the multifaceted fatigue profile observed during 90 min of soccer-specific exercise. However, no data currently exists which has profiled acid-base balance responses during prolonged durations of soccer-specific exercise (i.e., those games requiring an ET period). Therefore, the aim of this study was to investigate changes in acid-base balance across 120 min of simulated soccer match-play in professional academy soccer players. I hypothesised that ET would influence indices of acid-base balance relative to the demands of the previous 90 min.

6b.2 METHODS

6b.2.1 Experimental Approach to the Problem

To investigate the effects of 120 min of soccer-specific exercise on acid-base balance and sprint performance, eight professional academy soccer players completed a simulated soccer match with physiological measurements taken at regular intervals. The dependent variables included in this study were indices of exercise intensity and performance (i.e., 15-m sprint velocities, heart rate, rating of perceived exertion; RPE, blood calcium, and potassium concentrations); measures of acid-base balance (i.e., blood pH, base excess, lactate, haemoglobin, and bicarbonate concentrations); and hydration status (i.e., plasma and urine osmolality, plasma volume, and body mass changes).

6b.2.2 Subjects

This study received ethical approval from the Health and Life Sciences Ethics Committee at Northumbria University, Newcastle upon Tyne, UK. As part of a larger study design, eight male soccer players were recruited from an English Premier League club academy (mean ± SD; age: 16 ± 1 years, stature: 1.73 ± 0.05 m, mass: 68.5 ± 5.3 kg, estimated $\dot{V}O_{2\ max}$: 55 ± 9 $ml \cdot kg^{-1} \cdot min^{-1}$) and provided written informed consent. Parental consent was also sought as all players were under the age of 18 years. All players played for a professional soccer academy for > 12 months prior to the start of the study.

6b.2.3 Procedures

Players undertook two preliminary visits prior to the main trial. The first visit sought to estimate maximum oxygen uptake ($\dot{V}O_{2max}$) using the Yo-Yo intermittent recovery test one (Bangsbo et al., 2008) and the second visit habituated players with the main trial procedures. Players performed a coach-led 45 min tactical training session (involving positional and tactic-specific drills), abstained from caffeine ingestion, and completed self-reported food diaries (analysed retrospectively; Nutritics Ltd., UK) in the 24 h prior to the main trial. After an overnight fast, players arrived at the testing center at ~08:00 h and were asked to provide a mid-flow urine sample. A standardised breakfast (2079 kJ, 77.1 g carbohydrates, 12.3 g fats, and 14.3 g proteins) was provided to each player, including 500 ml of a fluid-electrolyte beverage (Mineral Water, Highland

Spring, UK) following a fingertip capillary blood sample. Measures of body mass and stature (Seca GmbH & Co., Germany) were then taken. Following a post-breakfast rest period of ~90 minutes, another fingertip capillary blood sample was taken. Players then undertook warm-up procedures consisting of speed drills, dynamic stretching, and ball work while drinking 200 ml of the fluid-electrolyte beverage.

Utilising a modified version of the Soccer Match Simulation (SMS; Russell et al., 2011b), a valid and reliable soccer-specific protocol (Russell et al., 2011a) players performed 120 min of soccer-specific activity, including intermittent exercise and ball dribbling. In line with FIFA regulations, the SMS was split into two 45 min halves separated by a 15 min break (half-time; HT) and two additional 15 min halves separated by a two min break (ET) (Figure 6b.1). Players ingested 500 ml of the fluid electrolyte beverage during HT. A five min passive rest period followed the initial 90 min period prior to ET. During this period, body mass was measured and players were provided with 200 ml of the fluid-electrolyte drink and two 66 g energy-free gels (High5 Ltd., UK). Players covered a total distance of ~14.4 km, reflective of a match requiring ET (Russell et al., 2015b) while intermittently performing 15 m sprints (Brower-TC Systems, Brower Timing Systems, USA) and ball dribbles through cones set over an 18 m distance.

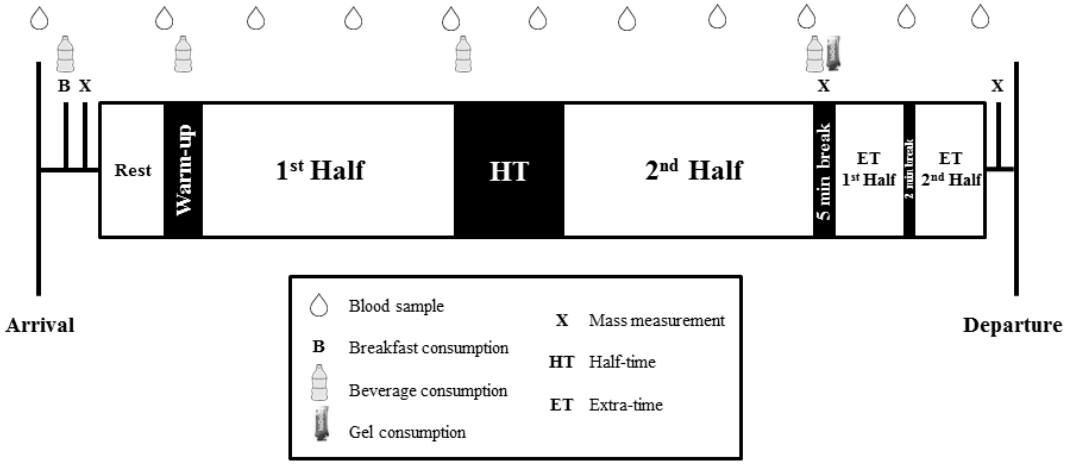


Figure 6b.1 Schematic of main trial procedures.

Capillary blood samples (170 µl) were collected from the fingertip upon arrival (baseline), pre-exercise (pre), HT and at 15, 30, 45, 60, 75, 90, 105 and 120 min (Figure 6b.1) and subsequently analysed for blood lactate, pH, haematocrit (Hct), bicarbonate ($HCO3^-$), calcium, and potassium concentrations (GEM Premier 3000; Instrumentation Laboratory, UK; CV's: 0.003-2.2%; Beneteau-Burnat et al., 2004). Haemoglobin (Hb) concentrations were also measured (Hemocue 201+; HemoCue AB, Sweden). Hct and Hb concentrations were used to measure plasma volume changes throughout exercise (Dill & Costill, 1974). Base excess concentrations were calculated using equation 1 according to the manufacturer's instructions (GEM Premier 3000; Instrumentation Laboratory, UK) using the values derived from $HCO3^-$, Hb, and pH:

Eq'n 1: Base Excess = (1 – 0.014 x Hb) x [$HCO3^-$ - 24 + (1.63 x Hb + 9.5) x (pH – 7.4)]

Urine and plasma osmolality (Advanced Model 3300 Micro-Osmometer; Advanced Instruments Inc., USA), urine-corrected mass changes, and ratings of perceived exertion (Borg, 1982) were recorded during each trial. Environmental

conditions were measured during exercise (Technoline WS-9032; Technotrade GmbH, Germany) and mean and peak heart rate (HR_{mean} and HR_{peak}, respectively) were recorded using short-range telemetry (Polar RS400; Polar Electro, Finland). A mid-flow urine sample was collected post-exercise and body mass was assessed before the players were allowed to leave the testing center.

6b.2.4 Statistical Analysis

Statistical analyzes were carried out using IBM SPSS Statistics software (Version 22.0; IBM Inc., USA). Data are reported as mean ± standard deviation (SD). Statistical power was calculated using commercially available software (GPower v3.1, Germany) and a sample size of eight was deemed sufficient for ≥ 70% power to detect statistical differences in pH, base excess, and 15 m sprint speed. Paired sample t-tests were performed for data with two time points (i.e. plasma and urine osmolality) and repeated measures analysis of variance (ANOVA) were conducted for data with more than two time points (i.e., exercise intensity and acid-base balance parameters). The Greenhouse-Geisser correction was applied if the assumption of sphericity was violated. Significant main effects of time were analysed *post-hoc* using a least significant difference (LSD) test. Relationships between 15 m sprint performance and changes in acid-base balance parameters were tested using a Pearson product-moment correlation coefficient. Significance was set at $p \leq 0.05$.

6b.3 RESULTS

Environmental conditions were 19.2 ± 1.5°C, 75 ± 8%, and 1017 ± 4 mmHg for ambient temperature, humidity, and barometric pressure, respectively. Dietary analyses revealed that the players were not taking any performance enhancing supplements and compromised of 8.5 ± 0.7 $MJ \cdot d^{-1}$, of which 42 ± 5%, 25 ± 1%, and 33 ± 6% of energy intake was obtained from carbohydrates, proteins, and fats, respectively.

6b.3.1 Exercise Intensity

Exercise influenced RPE with higher RPE values during ET (15 ± 4) compared to the first (10 ± 4) and second (12 ± 4) halves (both $p \leq 0.001$). RPE values were also higher during the second half compared to the first half ($p = 0.035$). Sprint velocities were lower during ET compared to the first (-7 ± 6%, $p = 0.021$) but not the second (-3 ± 4%, $p = 0.086$) half (Figure 6b.2). HR_{peak} and HR_{mean} remained the same throughout exercise ($F_{(2,14)} = 3.658$, $p = 0.063$, $\eta^2 = 0.343$ and $F_{(2,14)} = 2.973$, $p = 0.084$, $\eta^2 = 0.298$). Concentrations of blood calcium ($F_{(4,31)} = 1.081$, $p = 0.387$, $\eta^2 = 0.134$) and potassium ($F_{(3,23)} = 0.794$, $p = 0.520$, $\eta^2 = 0.102$) were not influenced by exercise (Table 6b.1).

Table 6b.1 Physiological variables as a function of timing throughout exercise (mean ± SD). Pre = pre-exercise and HT = half-time. a = significant difference from 120 min ($p < 0.05$). b = significant difference from 105 min ($p < 0.05$).

Variable	Baseline	Pre	15 min	30 min	45 min	HT	60 min	75 min	90 min	105 min	120 min	Timing Effect p value
Blood Lactate ($mmol \cdot l^{-1}$)	0.7 ± 0.2 ab	1.6 ± 0.7	3.4 ± 1.6 b	3.0 ± 1.2 b	3.1 ± 1.7	2.4 ± 0.5	2.4 ± 0.7	2.3 ± 0.7	2.4 ± 1.0	2.2 ± 0.7	3.3 ± 2.2	0.007
Blood Potassium ($mmol \cdot l^{-1}$)	4.4 ± 0.3	5.0 ± 0.8	4.8 ± 0.5	4.9 ± 0.3	5.0 ± 0.9	4.8 ± 0.3	4.9 ± 0.4	5.0 ± 0.6	5.0 ± 0.5	4.9 ± 0.4	5.1 ± 0.9	0.520
Blood Hb ($mg \cdot dl^{-1}$)	134 ± 6 a	133 ± 13 a	149 ± 10	145 ± 6	142 ± 4	139 ± 10	151 ± 9 b	152 ± 8 b	144 ± 12	143 ± 9	145 ± 12	≤0.0005
Blood Calcium ($mmol \cdot l^{-1}$)	1.20 ± 0.02	1.24 ± 0.05	1.23 ± 0.05	1.24 ± 0.02	1.23 ± 0.04	1.21 ± 0.01	1.22 ± 0.03	1.22 ± 0.03	1.23 ± 0.02	1.23 ± 0.02	1.22 ± 0.04	0.387

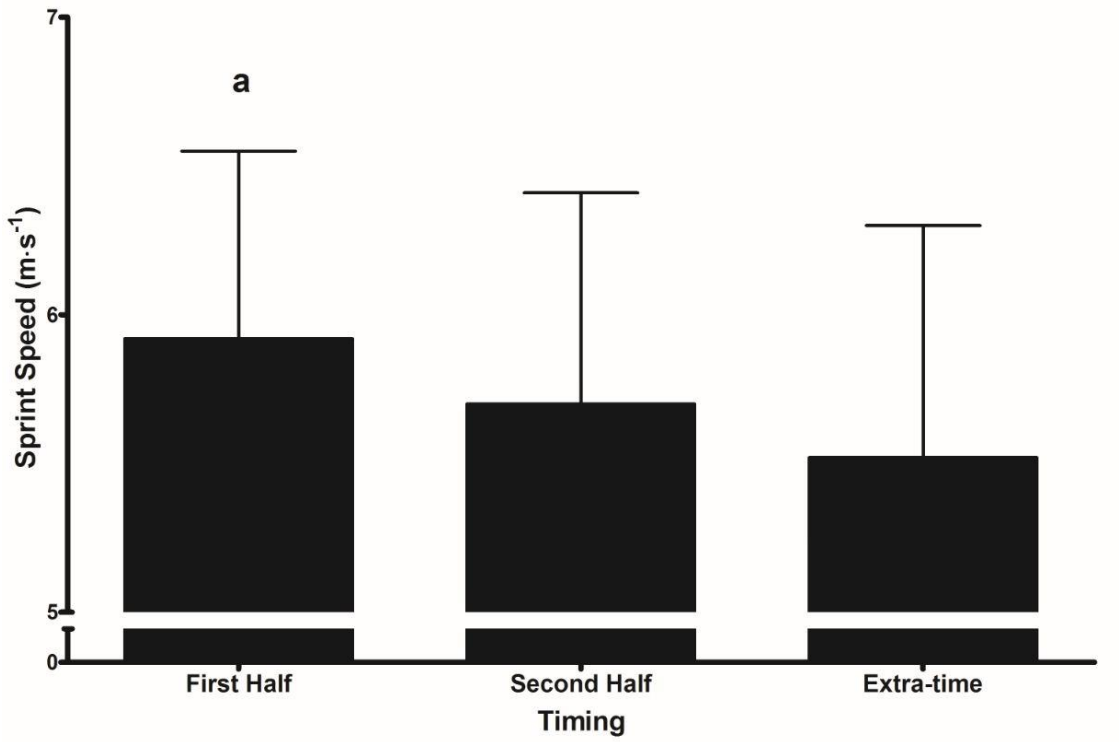


Figure 6b.2 Sprint velocities (15 m) during the trial (mean ± SD). a = significant difference compared to extra-time ($p < 0.05$).

6b.3.2 Acid-Base Balance Response

Exercise influenced blood lactate ($F_{(3,19)} = 5.834$, $p = 0.007$, $\eta^2 = 0.455$) and pH ($F_{(2,18)} = 3.192$, $p = 0.054$, $\eta^2 = 0.313$) responses. Blood lactate concentrations were lower at 105 min compared to 15 min (-27 ± 28%, $p = 0.022$) and 30 min (-26 ± 14%, $p = 0.009$) (Table 6b.1). At 105 min, blood pH was higher compared to 15 min (+0.4 ± 0.4%, $p = 0.011$) and 30 min (+0.4 ± 0.4%, $p = 0.030$), but lower compared to 75 min (-0.3 ± 0.2%, $p = 0.010$) (Figure 6b.3A). At 120 min, blood pH was lower compared to 105 min (-0.5 ± 0.4%, $p = 0.012$). Notably, blood pH was lower at 120 min compared to baseline (-0.3 ± 0.3%, $p = 0.015$), and HT (-0.4 ± 0.4%, $p = 0.017$) (Figure 6b.3A).

Exercise influenced base excess ($F_{(3,25)} = 6.107$, $p = 0.002$, $\eta^2 = 0.466$), $HCO3^-$ ($F_{(3,22)} = 5.802$, $p = 0.004$, $\eta^2 = 0.453$), and Hb concentrations ($F_{(5,32)} = 6.459$, $p \leq 0.0005$, $\eta^2 = 0.480$). Base excess concentrations at 120 min were lower than at

HT (-110 ± 159%, p = 0.013), during the whole of the second half (46-90 min, all p < 0.05) and at 105 min (-219 ± 280%, p = 0.001) (Figure 6b.4). Base excess at 105 min was also higher than at 15 min (+1011 ± 2307%, p = 0.031) and 60 min (+20 ± 143%, p = 0.031) values (Figure 6b.4). $HCO3^-$ concentrations were lower at 120 min compared to 105 min (-3.7 ± 3.3%, p = 0.017) and higher at 105 min compared to HT (-2.2 ± 1.4%, p = 0.003) (Figure 6b.3B). Hb concentrations were higher at 120 min compared to baseline (+6.8 ± 5.6%, p = 0.015) and pre-exercise (+7.9 ± 9.0%, p = 0.040) (Table 6b.1). Hb concentrations were also higher at 105 min compared to baseline (+6.1 ± 4.1%, p = 0.005) but lower at 105 min compared to both 60 min (-5.5 ± 5.2%, p = 0.019) and 75 min (-6.2 ± 5.8%, p = 0.019) (Table 6b.1). There were no significant correlations between changes in 15 m sprint performance and blood pH, lactate, Hb, base excess, or bicarbonate concentrations (all p > 0.05).

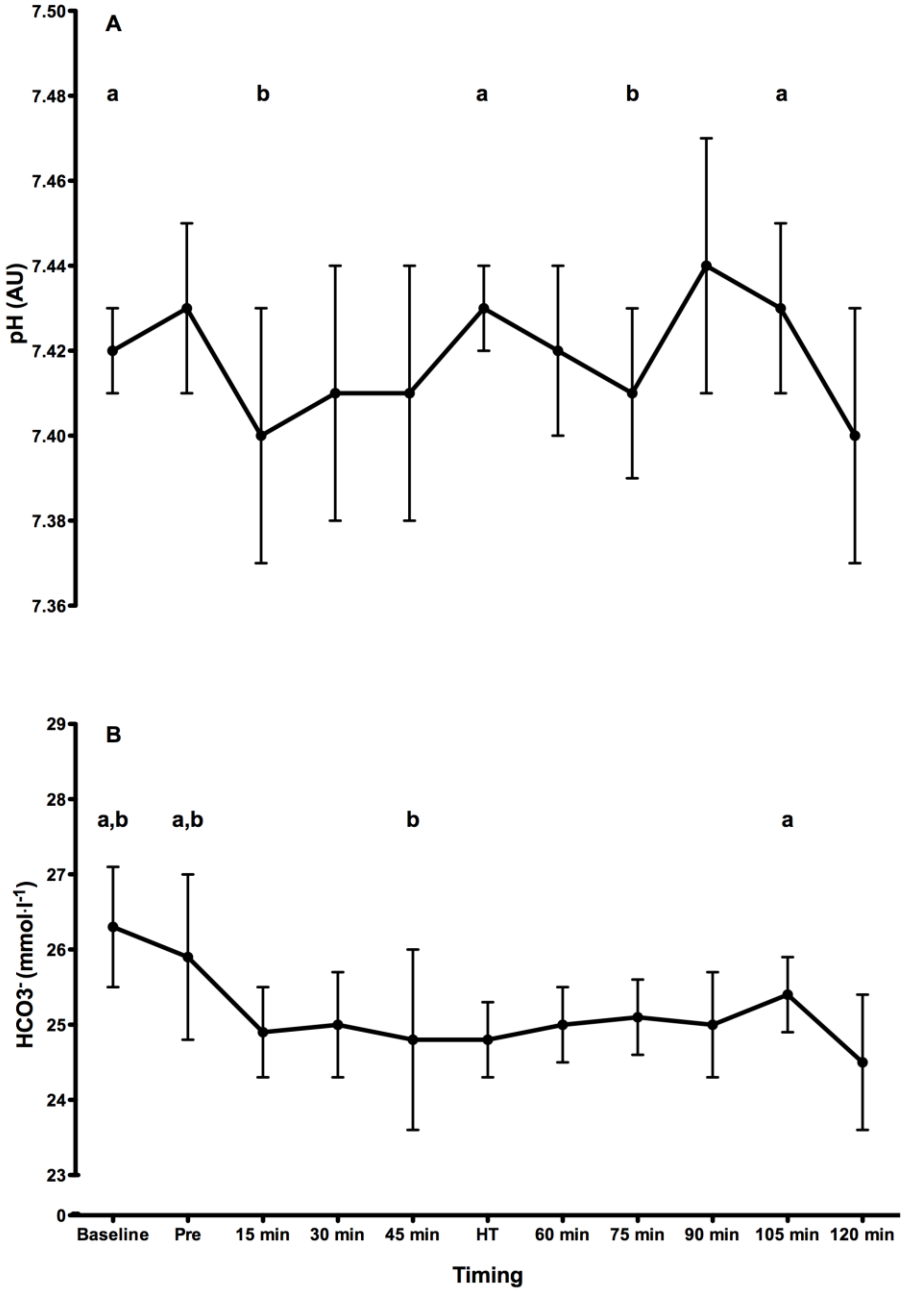


Figure 6b.3 Blood pH (A) and $HCO3^-$ (B) concentrations throughout the trial (mean ± SD). Pre represents pre-exercise and HT represents half-time. a = significant difference compared to 120 min ($p < 0.05$). b = significant difference compared to 105 min ($p < 0.05$).

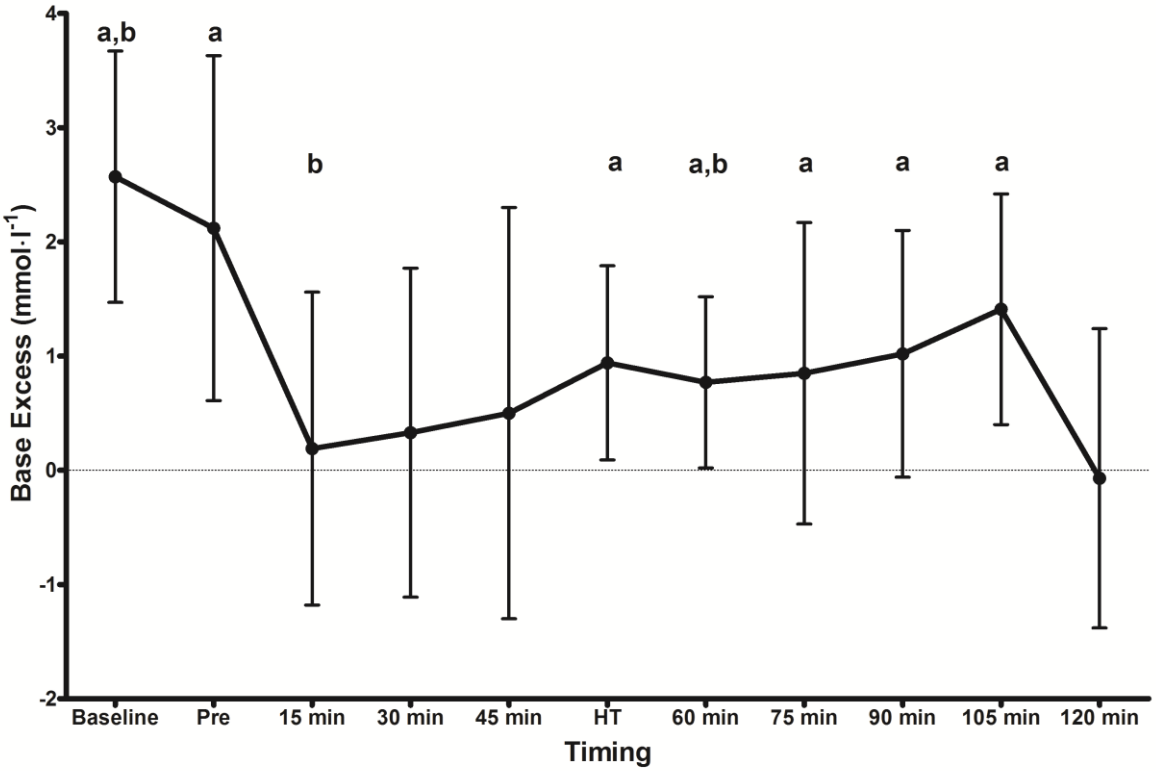


Figure 6b.4 Base excess concentrations throughout the trial (mean ± SD). Pre represents pre-exercise and HT represents half-time. a = significant difference compared to 120 min ($p < 0.05$). b = significant difference compared to 105 min ($p < 0.05$).

6b.3.3 Hydration Status

Exercise influenced body mass ($F_{(1,6)}$ = 28.337, p = 0.001, η^2 = 0.825) with participants exhibiting lower body mass values post-exercise (67.8 ± 5.1 kg) compared to both pre-exercise (69.1 ± 5.3 kg, p ≤ 0.0005) and 90 min (68.3 ± 5.1 kg, p = 0.015). Plasma volume was influenced by exercise ($F_{(4,25)}$ = 9.332, p ≤ 0.0005, η^2 = 0.571). Plasma volume was lower at 120 min (-7 ± 7%) compared to 105 min (-2 ± 7%, p = 0.048). Plasma volume was higher at 105 min compared to 15 min (-10 ± 6%, p = 0.014), HT (-3 ± 6%, p = 0.003), and 60 min (-11 ± 9%, p ≤ 0.0005). Urine osmolality was unchanged during exercise (p = 0.605), whereas plasma osmolality was higher post-exercise (330 ± 11 mOsmol·kg^{-1}) compared to pre-exercise (309 ± 6 mOsmol·kg^{-1}, p = 0.005).

6b.4 DISCUSSION

This is the first study to assess changes in acid-base balance during 120 minutes of soccer-specific exercise. In line with my hypotheses, ET influenced markers of acid-base balance, specifically; blood pH, $HCO3^-$, Hb, and base excess concentrations in eight English Premier League academy soccer players. However, the concentrations observed at 105 and 120 min would suggest that acid-base balance and buffering capacity are not compromised during ET. Furthermore, the lack of any significant correlation between changes in performance and the indices of acid-base balance measured may indicate performance was not modulated by changes in acid-base balance.

I observed reductions of 0.01-0.03 pH units in the last 15 min of ET compared to baseline, HT, and the first 15 min of ET (Figure 6b.3A). Despite the statistical significance of these findings, this magnitude of change in blood pH is unlikely to be the cause of the reduced physical performance observed in the present study (Figure 6b.2) and previous investigations on ET (chapters 4-6a). This is supported by the lack of any relationship between decrements in 15 m sprint performance and reductions in blood pH ($p > 0.05$). Furthermore, reductions in pH of <0.2 units are unlikely to reflect acidosis or cause a reduction in exercise performance (Cairns, 2006; Krustrup et al., 2015). Indeed, the previously held notion that acidosis limits exercise performance has been challenged (Mainwood & Renaud, 1985; Westerblad et al., 2002; Cairns, 2006) as contractility of mammalian muscle *in-vitro* is unaffected even at a pH as low as 6.67 units (Westerblad et al., 1997). Moreover, it has been postulated that intracellular acidosis may actually protect muscle function through its ameliorative effect on extracellular potassium accumulation (Nielsen et al., 2001). Therefore, the drops in blood pH observed are incongruous with metabolic acidosis and thus may not be a limitation during soccer-specific exercise.

Blood lactate concentrations did not exceed 3.4 ± 1.6 $mmol \cdot l^{-1}$ during exercise (Table 6b.1). Lactate concentrations of this magnitude are not reflective of those observed during exercise-induced acidosis (Robergs et al., 2014; Hanon et al., 2015). Despite being lower than during some previous investigations in soccer players (Bangsbo et al., 2007; Russell & Kingsley, 2012), the observed lactate

concentrations are comparable to those observed in Danish lower league players during a 90 min soccer match simulation (Bendiksen et al., 2012).

Blood lactate concentrations were lower during ET compared to the first 15 min of exercise (Table 6b.1). This may be indicative of a decelerated rate of substrate level phosphorylation during ET and a shift in substrate utilisation. Findings from chapter 5a show significant increases in plasma adrenaline, non-esterified fatty acids, and glycerol during ET with concomitant reductions in blood lactate and plasma insulin. As successful high-intensity exercise performance such as sprinting is reliant on glycogenolysis (Bangsbo, 1994; Reilly, 1997), an increased reliance on fat oxidation for fuel during ET may explain the reductions in 15 m sprint performance observed in the present investigation; however, this remains speculative. Future research opportunities therefore exist to assess transient changes in muscle glycogen concentrations during ET.

Total buffering capacity was influenced by exercise, with reductions in Hb (Table 6b.1), $HCO3^-$ (Figure 6b.3B), and base excess (Figure 6b.4) concentrations during the last 15 min of ET compared to earlier periods of exercise. Despite the presence of statistically significant differences, the relatively small changes in these variables may not indicate physiologically meaningful alterations in buffering capacity (Hanon et al., 2015). Furthermore, I observed no correlation between alterations in buffering capacity and reductions in sprint speed, possibly indicating performance was not influenced by changes in buffering. A previous study investigating acid-base balance changes across 90 min of simulated soccer match-play found much lower $HCO3^-$ values in the second half compared to any time point during exercise in the present investigation (Russell & Kingsley, 2012) despite the same method of analysis. This could be explained by the playing level and age of the player recruited. Blood bicarbonate concentrations observed in the present investigation are similar to those observed in male athletes performing high-intensity intermittent exercise while ingesting sodium bicarbonate (Krustrup et al., 2015).

Physical performance was negatively impacted during ET. Similar observations were found during simulated in chapters 5a, 5b and 6a, and during actual match-play (Lago-Penas et al., 2015; Russell et al., 2015b). Furthermore,

reductions in technical performance markers (i.e., the number of successful passes and dribbles) were observed in chapter 4. Moreover, Russell et al., (2015b) observed significant reductions in total distance covered, high intensity distance covered, and the total number of sprints, accelerations, and decelerations during an ET period in an English Premier League reserve match. Temporal fatigue during soccer match-play and simulated soccer exercise is likely to be multifactorial in origin, both during 90 min and ET (Krustrup et al., 2006; Reilly et al., 2008). Compromised muscle glycogen stores (Rollo, 2014), disturbances in muscle ion homeostasis (Mohr et al., 2003), and dehydration (Shirreffs et al., 2006) have all been linked to reduced soccer performance. ET negatively impacted both body mass and plasma osmolality. The players lost an additional 0.5 ± 0.4 kg of body weight in ET compared to 90 min and plasma osmolality was significantly higher post-exercise compared to baseline. This may indicate further dehydration in ET which could be a putative factor explaining the decrease in exercise performance (Shirreffs et al., 2006).

Although blood potassium was not influenced by exercise (Table 1), I observed individual values > 6 $mmol \cdot l^{-1}$ at 120 min, similar to those observed following an exhaustive Yo-Yo Intermittent Recovery Test (Krustrup et al., 2003). However, the mean value of all participants was 5.1 ± 0.9 $mmol \cdot l^{-1}$ (Table 6b.1), analogous with those observed during soccer match-play (Krustrup et al., 2006). It is unlikely that concentrations of blood potassium of this degree explain the reductions in performance (Krustrup et al., 2006). Further work is required to isolate the influence of muscle ion fluctuations on performance during an ET period. Due to a disassociation between interstitial and extracellular ionic concentrations, disturbances in muscle ion homeostasis are more reflective of fatigue than changes at the extracellular level (Nielsen et al., 2004; Cairns & Lindinger, 2008; Krustrup et al., 2015). Accumulation of inorganic phosphate (P_i) in the muscle has been implicated as the major factor in tempered force production and increased fatigue during exercise (Allen & Westerblad, 2001; Westerblad et al., 2002; Allen & Trajanovska, 2012; Debold, 2012); however, changes in P_i have yet to be explored during soccer-specific exercise of any duration.

6b.5 CONCLUSIONS

This data adds to the developing body of literature related to both the performance and physiological responses during simulated and actual match-play requiring a soccer ET period. Practitioners and coaches should be cognisant of the fact performance is adversely impacted by ET and potential methods of attenuating diminutions in performance should be sought (i.e., acute nutritional interventions and training programme design). The magnitude of the physiological changes observed as a consequence of 120 min of intermittent exercise in this study highlight that metabolic acidosis and perturbations in buffering capacity are not likely to be performance-limiting factors in ET. Further research utilising invasive techniques such as muscle biopsies to assess ionic, P_i and glycogen disturbances during 120 minutes of soccer match-play is required.

7.0
GENERAL DISCUSSION

7.0 GENERAL DISCUSSION

Primarily, the aims of this thesis were threefold: (i) gather information from professional practitioners regarding ET using qualitative analysis (ii) investigate the influence of ET on physiology and performance, and (iii) investigate the efficacy of a nutritional intervention in an attempt to ameliorate decrements in performance.

Findings from chapter 3 demonstrated that practitioners working in professional football believe ET is an important period of match-play to determine success, with some, but not all, adapting their preparation and recovery strategies before and after matches requiring ET. Notably, the majority of practitioners (91%) felt that more research was required on ET, particularly in the areas of fatigue responses and nutritional interventions.

Using a notational analysis technique in chapter 4, it was observed that indices of technical performance (specifically passing and dribbling) are negatively influenced by an ET period. Indeed, the number of successful passes and the total number of passes and dribbles are reduced during the last 15 min of ET compared to other 15 min periods throughout match-play. However, not all technical performance parameters were impacted, demonstrating a non-uniform response during 120 min of match-play.

Using an analogue of match-play (i.e., the SMS) during chapter 5a, diminutions in both physical and technical performances were observed during and after ET. Furthermore, aspects of physiology and metabolism were negatively affected during ET, indicating this additional period of play has consequences for both performance and physiology. In a separate sub-investigation (chapter 5b), the repeatability of the responses to 120 min of the SMS were demonstrated.

The major finding from chapter 6a was that carbohydrate-electrolyte gels provided in the five min break prior to ET increased blood glucose concentrations and improved dribbling performance but did not attenuate decrements in physical performance and hydration status. In the placebo arm of the study, additional blood parameters related to acid-base balance were analysed (chapter 6b). Changes in these parameters were not conducive with

metabolic acidosis or alterations in buffering capacity and thus unlikely to be associated with reductions in performance during ET.

The findings from the aforementioned studies will be discussed in this chapter. Evaluations of current knowledge will be made where appropriate and future research areas regarding ET will be discussed.

7.1 THE EFFECT OF EXTRA-TIME ON TECHNICAL PERFORMANCE

The importance of maintaining technical performance throughout match-play is a major contributor to match success (Lago-Penas et al., 2010). Gross motor skills such as shooting, dribbling, and passing will likely contribute to the outcome of a match as soccer is essentially decided by who can score the most goals, and the ability to execute a successful pass or dribble are part of the fundamental skillset of the sport (Stone & Oliver, 2009). Although literature exists on the influence of 90 min of actual or simulated soccer match-play on technical performance (i.e., Rampinini et al., 2009; Russell et al., 2011a), the studies within this thesis are the first to assess technical performance during ET.

Utilising a computer-based notational analysis procedure in chapter 4, it was observed that the total number of passes, number of successful passes, and number of successful dribbles were reduced by 17-32% during the last 15 min of ET compared to other 15 min periods of the 120 min match. Overall, 17 technical variables were measured and only four were influenced by ET (time of ball in play was also reduced during 105-119:59 min vs. 0-14:59 min). This lack of uniformity in response is congruent with previous investigations of 90 min duration (Rampinini et al., 2009; Russell et al., 2013). However, as passing and dribbling are fundamental to soccer performance, these findings have implications for global match performance.

Although shooting performance was unaffected in chapter 4; in chapter 5a, shot speed was reduced by ~5% at 120 min compared to all other time-points except pre-second half. As only shot frequency and accuracy was measured during chapter 4 this would explain this discrepancy. A reduction in shot speed has implications for the ability to score goals during ET, as slower shots will be easier to save by goalkeepers or blocked by defenders. As shot velocity is

linked to lower body power output (Cometti et al., 2001), this finding may indicate tempered muscle force at the end of ET compared to during 90 min. Furthermore, as shooting requires synergistic movement of the lower limbs, a reduction in joint positional sense and motor control may have impacted shot technique (Cometti et al., 2001). However, this had no influence on shooting precision or success.

In chapters 5a, 5b and 6a, dribbling performance was predominately unaffected by ET, with the only finding being more precise dribbles during ET compared to the first 15 min of exercise in chapter 5a. This aligns with the findings of studies during 90 min of match-play and also chapter 4 as although the total number of dribbles reduced, actual dribble proficiency (i.e., accuracy) was not affected. Therefore it would seem that players are able to maintain dribble proficiency throughout an ET period. Furthermore, dribble speed was maintained by participants in all studies, with no *speed-accuracy trade off* evident. Therefore the findings from chapter 4 could be attributed to match-related fatigue, as a reduction in the number of total passes and dribbles would indicate a diminution in the number of involvements with the ball and thus an inability to maintain the prior intensity of match-play. Findings to support this hypothesis during 90 min are equivocal. Indeed, in players who were considered fatigued, Rampinini et al. reported between-half reductions of 12 to 16% in the number of technical actions performed per player in the Italian Serie A league (Rampinini et al., 2009). However, it is prudent to note that decreases in physical performances observed in French Ligue 1 midfield players was not accompanied by reduced technical performance (Carling & Dupont, 2011). Nevertheless, in chapters 5a-6b, physical performance measures were assessed during the SMS throughout the 120 min of simulated match-play.

7.2 THE EFFECT OF EXTRA-TIME ON PHYSICAL PERFORMANCE

Due to the intermittent nature of soccer, maintaining physical performance throughout match-play is a fundamental aspect of overall match performance (Reilly et al., 2008). Thanks to the diligent work of a number of researchers in the past four decades, the physical demands of 90 min of match-play are now well known (Mohr et al., 2003; Stolen et al., 2005; Bradley et al., 2016). However, despite the existence of a large body of literature quantifying the

demands of 90 min of soccer, there is a paucity of data regarding matches that are 120 min in duration (i.e., require ET). Therefore the findings from this thesis add to the small body of existing literature (i.e., two published journal articles – Lago-Penas et al., (2015); Russell et al., (2015)).

Throughout the studies utilising the SMS in this thesis (i.e., chapters 5a-6b), similar changes in physical performance were observed. Changes in sprint velocities over 15 m were uniform throughout the studies. When broken down into three periods (i.e., first half, second half and ET) or split into 15 min epochs, 15 m sprint velocities were 3-8% lower during ET compared to all other time-points. This represents a novel finding that ET causes further perturbations in the ability to maintain sprint speed during simulated match-play. These findings align with published data from actual match-play requiring ET (Lago-Penas et al., 2015; Russell et al., 2015). Lago-Penas and colleagues observed top speed was lower during the ET period of professional match-play compared to the first 45 min, and maximal running speed was lower in ET compared to both the first and second halves (Lago-Penas et al., 2015). Furthermore, Russell et al. detected reductions in total distance covered, high-intensity distance covered, and the number of sprints, accelerations, and decelerations in the last 15 min of ET compared to the last 15 min of normal time (i.e., 76-90 min) during an English Premier League Reserve cup match (Russell et al., 2015b).

A non-uniform response between studies was observed for the RSA performance test. Sprint velocities over 20 m were reduced in chapter 5a at 120 min compared to all other time-points, however; in chapter 5b they were reduced only compared to baseline and post-first half. In chapter 6a, a 30-m sprint distance was used and sprint velocities were only significantly lower at 120 min compared to baseline. These discrepancies may have been due to the level of participant (i.e., professional academy soccer players used in chapter 6a) or insufficient statistical power to detect a change in this variable ($n = 10$ in chapter 5b and $n = 8$ in chapter 6a vs. $n = 22$ in chapter 5a). Although players were unable to maintain 15 m sprint velocities from the last 15 min of normal time (i.e., 76-90 min) during ET, they were able to produce similar velocities in isolated repeated sprint tests at 90 min and at 120 min over a longer distance. This discrepancy is difficult to explain, and may be due to the brief rest periods separating the end of the SMS and the beginning of the RSA test; allowing a

degree of physiological recovery. The 15 m sprint efforts are included within the movement pattern of the protocol and therefore there is a requirement for sustained intermittent exercise activity before and after each sprint.

An ET period did not seem to modulate CMJ height. In chapters 5a and 6a no changes in CMJ height were detected at 120 min compared to any other time-point. However, in chapter 5b, CMJ height was lower at 120 min compared to baseline. Although previous findings from studies investigating changes in jump height following 90 min of simulated soccer-match play remain equivocal (Thorlund et al., 2009; Robineau et al., 2012; de Hoyo et al., 2016; Stone et al., 2016), the findings from this thesis suggest that players are able to preserve jump performance throughout simulated match-play (no changes were detected at 90 min vs. other time-points). However, it should be noted that jump heights were lower following a 15 min passive HT period in all studies compared to baseline and post-first half. The mandated HT period in soccer has been previously shown to have deleterious effects on soccer-specific performance (Mohr et al., 2005; Weston et al., 2011; Lovell et al., 2013), with putative mechanisms including a decrease in muscle and core temperature (Mohr et al., 2004), and changes in glycaemia (Russell et al., 2015c). Interventions that attenuate these decrements in performance such as passive heat maintenance (Russell et al., 2015c), active re-warm-ups (Edholm et al., 2014), hormonal priming (Cook & Crewther, 2012), and caffeine/carbohydrate ingestion (Ryan et al., 2013; Russell et al., 2015c) warrant further investigation (Russell et al., 2015c).

7.3 THE EFFECT OF EXTRA-TIME ON PHYSIOLOGY AND METABOLISM

The aetiology of soccer-specific fatigue and the precise mechanisms associated with a decline in performance are not fully understood. Previous work on 90 min of soccer has posited roles for the degradation of endogenous fuel sources (Bendiksen et al., 2012), disturbances in muscle ionic balance (Krustrup et al., 2006), dehydration (Laitano et al., 2014), and shifts in substrate utilisation (Rollo, 2014) for the decline in performance. In this thesis it has been shown that ET elicits further decrements in both physical and technical performance compared to 90 min only. Throughout these investigations, physiological and metabolic measures have also been taken to assess changes in markers

associated with hydration status, glycemia, substrate use, exercise intensity, and acid-base balance.

Despite all studies using an ecologically valid fluid provision strategy, body mass losses following ET were approximately 2-3% compared to pre-exercise and 0.5-1% compared to 90 min. This would indicate ET causes further progressive dehydration. As dehydration has been shown to negatively impact soccer-specific performance (McGregor et al., 1999; Laitano et al., 2014) this may be a factor associated with the reduced performances observed in ET. Changes in body mass were also accompanied by increases in plasma osmolality and blood sodium concentrations, further illustrating increased dehydration during ET.

In chapter 5a, a number of metabolites associated with substrate use and exercise intensity were measured. Blood glucose concentrations were reduced in ET compared to during 90 min. Falls in blood glucose were accompanied by depressed insulin and lactate concentrations, with concomitant twofold increases in adrenaline compared to 90 min. Furthermore, plasma NEFA and glycerol concentrations were elevated throughout ET compared to the last 15 min of normal time. These metabolic changes are indicative of a shift in substrate utilisation during ET, and a taxing of endogenous fuel sources (i.e., muscle glycogen).

Elevated adrenaline concentrations both promote muscle glycogenolysis through its downstream activation of phosphorylase α (Watt et al., 2001), as well as activating adipose tissue hormone-sensitive lipase and mediating adipocyte lipolysis (Vaughan & Steinberg, 1963). This data also suggest lipolysis is further stimulated by dampened insulin concentrations in ET, as insulin is a major inhibitor of lipolysis partly through its activation of Akt and suppression of protein kinase A (Choi et al., 2010). The observed lower blood lactate concentrations in ET provide further evidence for a shift from substrate level phosphorylation to fat oxidation as a match progresses. These changes are likely to be compensatory mechanisms for the progressive decline in muscle glycogen during soccer match-play so as to maintain blood glucose concentrations.

The findings from chapter 5a were reproduced in chapter 5b, were not only was the repeatability of the protocol found but also similar decrements in performance and perturbations in physiology. However, in chapter 6a, glucose concentrations were consistent throughout 120 min of exercise, which may be explained by the different source of blood analysed (i.e., capillary vs. venous; Colagiuri et al., 2003); or the level of player (i.e., professional vs. university-standard). Overall, these changes in substrate utilisation are likely to impact on the ability to perform bouts of high-intensity running, which are crucial for successful soccer performance (Reilly, 1997; Faude et al., 2012).

Although changes in acid-base balance and potassium concentrations have been previously thought to impact soccer-specific performance (Bangsbo et al., 2006; Russell et al., 2012) the data from this thesis suggests that metabolic acidosis and modulations in buffering capacity are not apparent in ET and unlikely to explain reductions in performance. Furthermore, it has been demonstrated that the blood potassium concentrations detected in ET are not indicative of fatigue. However, as there is dissociation between ionic changes at the intracellular and extracellular level, further work is required to monitor ionic changes in the musculature during ET.

7.4 EFFECT OF CARBOHYDRATE PROVISION ON PERFORMANCE IN EXTRA-TIME

In chapter 6a a nutritional intervention strategy was applied (i.e., acute carbohydrate provision) in an aim to ameliorate decrements in performance. However, physical performances were not different between the carbohydrate trial and the placebo trial, despite elevated blood glucose concentrations. Providing carbohydrate did improve dribbling precision however, exhibiting a role for enhanced glucose concentrations in increasing cerebral glucose supply (Duell & Kuschinsky, 2011), improving motor control and maintaining central nervous system integrity (Nybo, 2003). This was despite participants being euglycemic when the carbohydrate was provided.

The inability for this carbohydrate to improve physical performance may be due to muscle glycogen concentrations in specific type II fibres reaching a level whereby high-intensity exercise is compromised (Greenhaff et al., 1994; Nielsen et al., 2011), with an acute increase in blood glucose unable to provide

additional substrate for site-specific glycogen resynthesis or anaerobic glycolysis (Romijn et al., 1993). However, it should be noted that as fatigue is a multifactorial phenomenon, changes in glucose and glycogen might only be part of the milieu of potential fatiguing mechanisms (Hargreaves et al., 1998). Further investigations are required with carbohydrate feeding during the warm-up, at HT and prior to ET to potentially preserve muscle glycogen concentrations in anticipation for an ET period.

7.5 DIRECTIONS FOR FUTURE RESEARCH

Through a review of the literature and investigations of the ET period, this thesis has highlighted future avenues for research. The findings from chapter 3, where 46 practitioners working in professional football were asked to complete an online survey, particularly highlight the need for future research and which particular areas are most relevant.

Nutritional interventions were considered the most important research area. In this thesis it has been demonstrated that providing carbohydrate in gel form prior to an ET period (a common practice in applied soccer) does not attenuate decrements in performance. Further work is required to not only optimise match-day nutrition but also nutrition in both the days preceding and succeeding a match that may require ET. Indeed, practitioners also see recovery modalities as an important research area. A number of nutritional strategies used to enhance recovery from exercise have been investigated, including functional foods (i.e., tart cherries and beetroot; Bell et al., 2016; Clifford et al., 2016), and protein and carbohydrate (Gunnarsson et al., 2013). The efficacy of these strategies in accelerating recovery following matches requiring ET warrants investigation. Other modes of recovery such as cold-water immersion (Ingram et al., 2009), compression garments (Nedelec et al., 2013), electrical stimulation (Taylor et al., 2015) and cryotherapy (Russell et al., 2016) also present themselves as future research opportunities.

Prior to the assessment of the efficacy of these recovery strategies, profiling the recovery response in the immediate (i.e., post-match) and prolonged period (i.e., +24 and +48 h) is required, particularly compared to 90 min of simulated or actual match-play in the same group of players. Furthermore, the physiological, physical and technical demands of ET during actual match-play requires further

investigation as the present literature (i.e., this thesis and Lago-Penas et al., 2015 and Russell et al., 2015b) is limited in comparison to the volume of literature profiling the demands of 90 min of match-play. This would provide more information to coaches and practitioners, as well as governing bodies who may use it to influence decisions such as permanently allowing a fourth substitute during ET. Practitioners should also seek to individualise their approach to ET, by identifying individuals who may be particularly susceptible to fatigue during ET.

Although governing bodies continue to debate the current regulations of ET and adjust the existing rules (for example the introduction of a fourth substitute during ET in the later rounds of the English FA Cup in July 2016) the data presented in this thesis provides information regarding what players may encounter when completing 120 min of a match. However, further investigations are required to further understand important areas of soccer and ET. Future work regarding the influence of ET on injury risk is required. Injuries are a serious issue in soccer, creating both performance- and economic-based issues for coaches and clubs (Bengtsson et al., 2013; Ekstrand, 2013). The effect of an ET period on acute injury risk both during and following a match requires investigation. Furthermore, epidemiological data regarding the frequency of injuries during ET and during training and matches in the days following a match that has gone to ET compared to 90 min matches should be sought. Finally, the impact of the environment (i.e., temperature and altitude) during matches requiring ET should be assessed. Important matches requiring ET have been played, and will be played in the future in hot and hypoxic environments. Creating a greater understanding of the influence of these conditions on match performance and player health is necessary.

8.0
APPENDICES

8.1 Appendix 1 Health Questionnaire/Informed Consent/Human Tissue

Health Questionnaire and Informed Consent

		Yes	No
1.	Are you older than 69?	☐	☐
2.	Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?	☐	☐
3.	In the past month, have you had chest pain when you were not doing physical activity?	☐	☐
4.	Do you lose your balance because of dizziness or do you ever lose consciousness?	☐	☐
5.	Do you have a bone or joint problem that could be made worse by a change in your physical activity?	☐	☐
6.	Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?	☐	☐
7.	Do you know of any other reason why you should not do physical activity?	☐	☐

Declaration:

Please sign below to confirm that you have answered questions 1-7 honestly.

Name _____

Signature _____ Date _____

Signature of Parent or Guardian (if under 18 years) _____ Date _____

AHA/ACSM Health/Fitness Facility Pre-participation Screening Questionnaire.

Name: .....
Address: .....
.....
Tel. Number: .....
Emergency Contact Name: ..... Tel No.: .....

Assess your health needs by marking all *true* statements.

History

You have had:

- ❒ a Heart Attack;
- ❒ Heart Surgery;
- ❒ Cardiac Catheterization;
- ❒ Coronary Angioplasty (PTCA);
- ❒ Pacemaker/implantable cardiac defibrillator/rhythm disturbance;
- ❒ Heart valve disease;
- ❒ Heart failure;
- ❒ Heart transplantation;
- ❒ Congenital heart disease.

*If you marked any of the statements in this section, consult your healthcare provider before engaging in exercise. You may need to use a facility with a **medically qualified staff**.*

Cardiovascular risk factors

- ❒ You are a man older than 45 years.
- ❒ You are a woman older than 55 years or you have had a hysterectomy or you are post-menopausal.
- ❒ You smoke.
- ❒ Your blood pressure is greater than 140/90.
- ❒ You don't know your blood pressure.
- ❒ You take blood pressure medication.
- ❒ Your blood cholesterol level is >240 mg/dL.
- ❒ You don't know your cholesterol level.
- ❒ You have a close blood relative who had a heart attack before age 55 (father or brother) or age 65 (mother or sister).
- ❒ You are diabetic or take medicine to control your blood sugar.
- ❒ You are physically inactive (i.e., you get less than 30 minutes of physical activity on at least 3 days per week).
- ❒ You are more than 20 pounds overweight.

***Symptoms* and other health issues:**

- ❒ You experience chest discomfort with exertion.
- ❒ You experience unreasonable breathlessness.
- ❒ You experience dizziness, fainting, blackouts.
- ❒ You take heart medications.
- ❒ You have musculoskeletal problems.
- ❒ You have concerns about the safety of exercise.
- ❒ You are pregnant.
- ❒ You take prescription medication(s).

*If you marked two or more of the statements in this section, you should consult your healthcare provider before engaging in exercise. You might benefit by using a facility with a **professionally qualified exercise staff** to guide your exercise program.*

❒ **None of the above is true**.

You should be able to exercise safely without consulting your healthcare provider in almost any facility that meets your exercise program needs.

AHA/ACSM indicates American Heart Association / American College of Sports Medicine

School of Life Sciences

FOR USE WHEN TISSUE IS BEING REMOVED AND STORED

Principal Investigator: Liam Harper

Participant Number: _____

I agree that the following tissue or other bodily material may be taken and used for the study:

Tissue/Bodily material	Purpose	Removal Method
Whole Blood	Blood glucose, lactate, adrenalin, interleukin-6 glycerol, non-esterified fatty acid	Intravenous/cannulation

I understand that if the material is required for use in any other way than that explained to me, then my consent to this will be specifically sought. I understand that I will not receive specific feedback from any assessment conducted on my samples, but should any kind of abnormality be discovered then the investigator will contact me.

I understand that the University may store this tissue in a Licensed Tissue Bank only for the duration of the study, it will then be destroyed.

Method of disposal:

Clinical Waste X

I consent to the University distributing this tissue to partners in this research study, outside of the University, for further testing (please tick the box if you agree). ☐

Signature of participant..... Date.....

Signature of researcher..... Date.....

INFORMED CONSENT FORM

Principal Investigator: Liam Harper

Participant Number: _____

please tick where applicable

I have read and understood the Participant Information Sheet.	☐
I have had an opportunity to ask questions and discuss this study and I have received satisfactory answers.	☐
I understand I am free to withdraw from the study at any time, without having to give a reason for withdrawing, and without prejudice.	☐
I agree to take part in this study.	☐
I would like to receive feedback on the overall results of the study at the email address given below. I understand that I will not receive individual feedback on my own performance. Email address……	☐

Signature of participant..... Date.....……..

(NAME IN BLOCK LETTERS).....……

Signature of Parent / Guardian in the case of a minor

.....

Signature of researcher..... Date.....……..

(NAME IN BLOCK LETTERS).....……

8.2 Appendix 2 Food Diary Example

DAY 1

Date: / /

Please use a separate line for each item eaten; write in weight of plate; leave a line between different 'plate' entries.

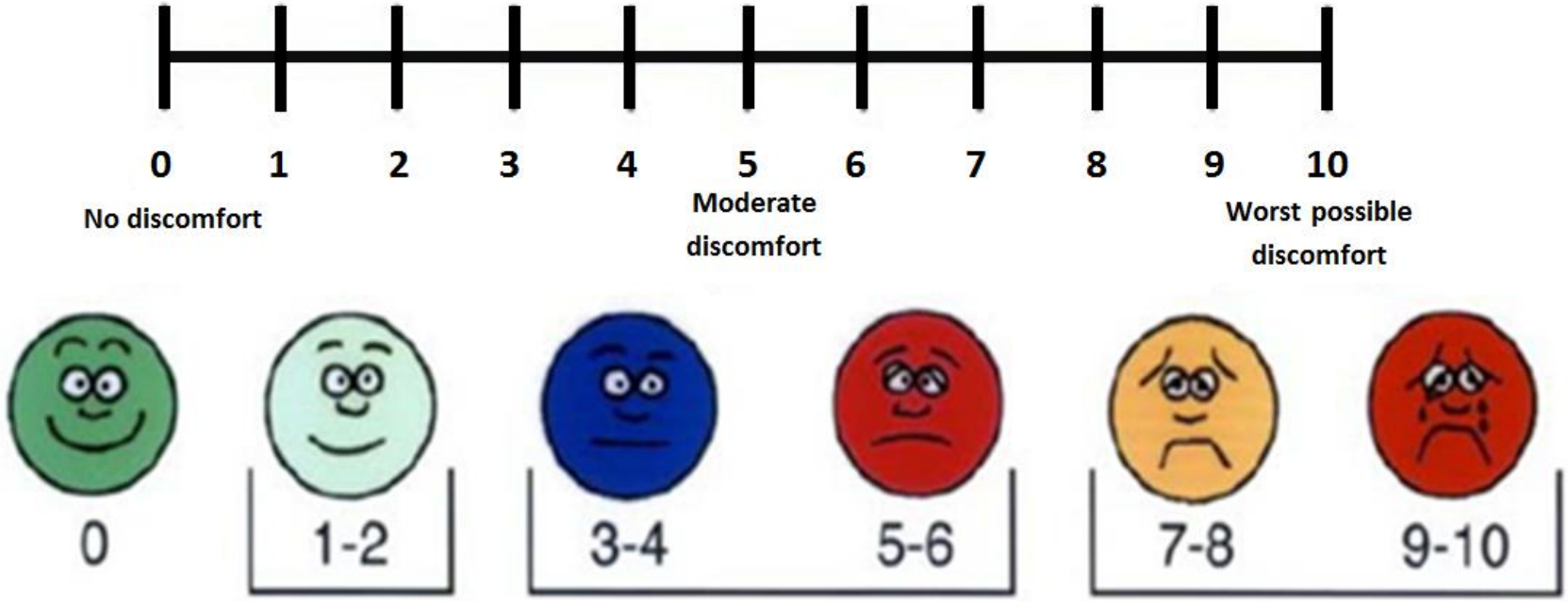
A	B		C	D	E	F	Office Use
Time	Food eaten		Brand name of each item (except fresh food)	Full description of each item including: -whether fresh, frozen, dried, canned -cooked: boiled, grilled, fried, roasted. -what type of fat food fried in	Weigh t Served	Weight of Leftovers	Actual Weight
am/p m	home	away			(gms)	(gms)	(gms)

8.3 Appendix 2 Rating of perceived exertion scale (Borg, 1982)

RATING OF PERCEIVED EXERTION

6	**NO EXERTION AT ALL**
7	
8	**EXTREMELY LIGHT**
9	**VERY LIGHT**
10	
11	**LIGHT**
12	
13	**SOMEWHAT HARD**
14	
15	**HARD**
16	
17	**VERY HARD**
18	
19	**EXTREMELY HARD**
20	**MAXIMAL EXERTION**

8.4 Appendix 3 Abdominal comfort scale (adapted from Price et al., 2003)



8.5 Appendix 4 Online survey questions

Supplementary Materials

Survey Questions

1. How much do you agree with the following statement?

"Extra-time is an important period for determining success in football match play"

Strongly Disagree Disagree Neither Agree or Disagree Agree Strongly Agree

2. Do you account for the potential of an extra-time period in the training and preparation of players?

Yes **No**

If **yes**, please specify and if **no**, please provide information as to why not.

3. On a game-day involving a match that may require extra-time to be played, do you prepare in a different way to the preparations before a normal match (i.e., a league match)?

Yes **No**

If **yes**, please specify what you do differently and if **no**, please provide information as to why not.

4. From the following options and in order of importance (1 being highest) what do you typically advocate to players during the break that separates the end of 90 minutes and the beginning of the extra-time period? Please choose from: **energy provision** (e.g., sports gels, carbohydrate drinks), **hydration** (e.g., water), **massage** (including attempts to relieve muscle cramps), **tactical preparations** (e.g., formation, instructional advice, preparation for penalties), or **other** (please state)?

5. Do you consider the short break between each 15 minute half of extra-time a potential time to implement any of the strategies mentioned in the previous question?

Yes **No**

If **yes**, please specify which of the options in the previous question is the most important at this time point and if **no**, please provide information as to why not:

6. If a match does go to extra-time, does this affect the recovery practices performed in the immediate (e.g., same day) and prolonged (e.g., +24 and +48 hour) periods after the match? i.e., influence on recovery modalities and training prescription.

Yes **No**

If **yes**, what changes are made and if **no**, please explain why recovery practices are not modified (e.g., what barriers exist?)?

7. Following on from the previous question, what changes would you make related to recovery if given the choice? Please be specific and list these in level of importance (1 being highest).

8. FIFA are currently considering allowing a fourth substitution during extra-time. Do you believe this is warranted?

Yes **No**

If **yes**, why and if **no**, please provide information as to why not:

9. What are your perceptions about the effectiveness of hydro-nutritional extra-time interventions (i.e., carbohydrate gel/drink consumption)?

Very Important Important Somewhat Important Not Important Not Sure

Do you advocate any particular nutritional supplementation before or during extra-time?

Yes **No**

If **yes**, what do you recommend and if **no**, please provide information as to why you don't:

10. Do you believe the use of nutritional products prior to extra-time is more important than any other time point (i.e., immediately pre-match, half-time etc.)

Yes **No**

If **yes**, please specify why and if **no**, please provide information as to why you don't.

11. Do you believe more research should be conducted into the extra-time period?

Yes **No**

If you chose **yes** please specify your perceived importance of the following areas to yourself, other members of coaching staff and the athletes.

	Very Important	Important	Somewhat Important	Not Important	Not Sure
Fatigue responses	□	□	□	□	□
Nutritional interventions	□	□	□	□	□
Training paradigms	□	□	□	□	□
Recovery modalities	□	□	□	□	□
Environmental considerations (i.e., heat and altitude)	□	□	□	□	□
Injury epidemiology	□	□	□	□	□
Acute injury risk	□	□	□	□	□

Are there any other areas not mentioned that you believe are important?

If you chose **no**, why do you believe the extra-time period should not be researched further?

9.0

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